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San Diego County Greenhouse Gas Inventory



**An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets**



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For an electronic copy of this summary report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.



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Key Findings

- San Diego County emitted 34 million metric tons of carbon dioxide equivalent (MMT CO₂E) in 2006 – an 18% increase over 1990 levels, commensurate with population growth during the same period.
- In 2006, per-capita emissions for San Diego County were 12 metric tons CO₂E, which is slightly lower than California as a whole (13) and significantly lower than the U.S. levels (24).
- In 2006, emissions from cars and light-duty trucks represented 46% of total greenhouse gas emissions in San Diego County.
- By 2020, under a business-as-usual scenario, regional greenhouse gas emissions are expected to be 43 MMT CO₂E, an increase of 9 MMT CO₂E (26%) over 2006 levels and 14 MMT CO₂E (48%) over 1990 levels.
- To meet AB 32 emissions reduction targets (1990 levels by 2020), San Diego County would have to reduce emissions by 14 MMT CO₂E (33%) below projected business-as-usual levels in 2020.
- Nearly 60% of total regional emissions are associated with individuals (e.g., passenger vehicles, light-duty trucks, residential electricity and natural gas consumption).
- San Diego County likely can reduce its greenhouse gas emissions to 1990 levels by 2020 through a combination of reduction strategies from all sectors. This study estimates that through a combination of 21 strategies, the region could reduce its emissions by 15 MMT CO₂E by 2020, more than the quantity required to reach 1990 levels.
- In the scenario above, reductions from the on-road transportation sector (7 MMT CO₂E) and the electricity sector (5 MMT CO₂E) represent 81% of total reductions.
- Two statewide policies would account for 41% of these greenhouse gas emissions reductions. Implementing the Pavely (AB 1493) vehicle emissions standards by 2020 would reduce emissions by just over 3 MMT CO₂E, 21% of total reductions, and implementing a 33% renewable portfolio standard by 2020 would reduce emissions by 3 MMT CO₂E, 19% of total reductions.

Report Overview

This study developed a greenhouse gas inventory for San Diego County to better understand the emissions sources in the region and to serve as a resource for local and regional decision makers as they consider ways to reduce emissions at the local and regional levels. To that end, the project team calculated historical greenhouse gas emissions from 1990 to 2006 using the best available data, and then estimated future emissions to 2020 for San Diego County. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, the study also sought to establish emissions reductions targets for the region. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions



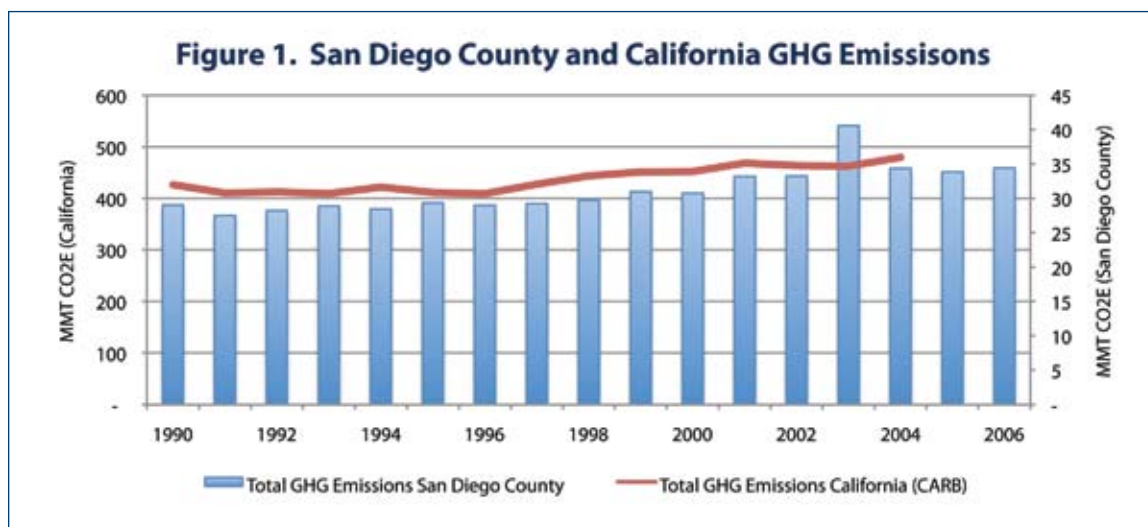


by a specific amount, the study calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to reduce emissions to 1990 levels by 2020—the statewide statutory target under AB 32. Finally, the study sought to identify and quantify potential emissions reduction strategies to determine the feasibility of reducing emissions to 1990 levels by 2020.

To the extent possible, the study followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide greenhouse gas inventory. In some instances, when doing so could yield a more accurate or precise result, the project modified the CARB method. This summary report is intended as an overview of the findings from the inventory, and no discussion of method is included. It provides information about the total greenhouse gas emissions for San Diego County and a summary of the highest emitting categories, including on-road transportation, electricity, and natural gas end-use consumption. It also gives an overview of the emissions reduction strategy analysis for each category of the inventory. Detailed analysis for each emissions category, including emissions levels, emissions reduction strategies (wedges), and detailed methodologies for calculating emissions are provided in eight supplemental reports available for download on the Energy Policy Initiatives Center Web site.¹

Greenhouse Gas Emissions in San Diego County

In 2006 San Diego County emitted 34 million metric tons of carbon dioxide equivalent (MMT CO₂E), an increase of 5 MMT CO₂E (18%) over 1990 level emissions.² This increase is commensurate with growth in regional population, which increased at the same rate during this period. Statewide emissions grew at rate of about 12% during this same period. Though this is slightly lower, the general trends have been similar. Figure 1 shows San Diego County and California statewide greenhouse gas emissions from 1990 through 2006. Note that 2003 emissions are significantly higher due to the wildfires in San Diego County that year.



1. Detailed reports are available at www.sandiego.edu/epic/ghginventory.
2. Carbon dioxide equivalent includes the sum of all greenhouse gases converted to the global warming potential (GWP) of carbon dioxide. For example, the GWP for methane is 21. This means that 1 million metric tons of methane is equivalent to emissions of 21 million metric tons of carbon dioxide.

Greenhouse gas emissions in San Diego County are primarily the result of energy use, 91% of total emissions are associated with fuel use. Figure 2, compares emissions in the four principal categories established by the United Nations Intergovernmental Panel on Climate Change (IPCC).

Dividing San Diego County greenhouse gas emissions by economic sectors, as shown in Figure 3, reveals that the residential sector is responsible for more than half of all San Diego County emissions. When aggregated, the impact of individual actions on San Diego County's regional greenhouse gas levels is significant. The combination of passenger vehicles, light-duty trucks, residential electricity use, and natural gas consumption accounts for about 19 MMT CO₂E, or 56% of total emissions. These are the sectors for which residential data are readily available, and it assumes that all light-duty trucks are used by individuals rather than by the commercial or industrial sectors.³ It is possible that a portion of passenger vehicles and light-duty trucks are used for commercial and industrial purposes, which would lower this estimate, but it is also true that the portion of civil aviation and waste attributable to individuals would increase slightly the estimated impact of individuals.⁴

Figure 2. 2006 San Diego County GHG Emissions by IPCC Category

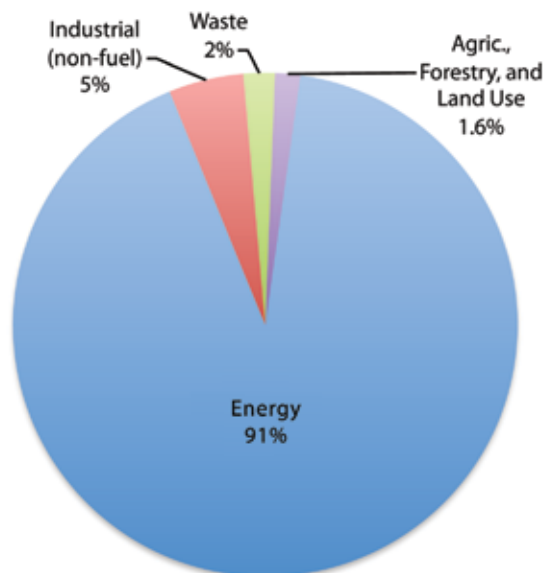
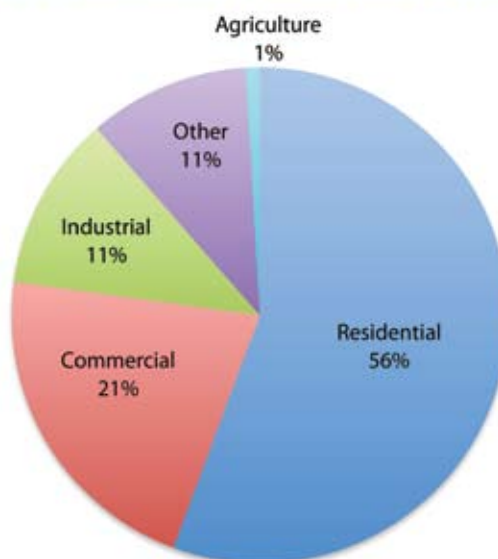


Figure 3. 2006 San Diego County GHG Emissions by Economic Sector



3. This is consistent with CARB's designation of these vehicle categories as "non-commercial."

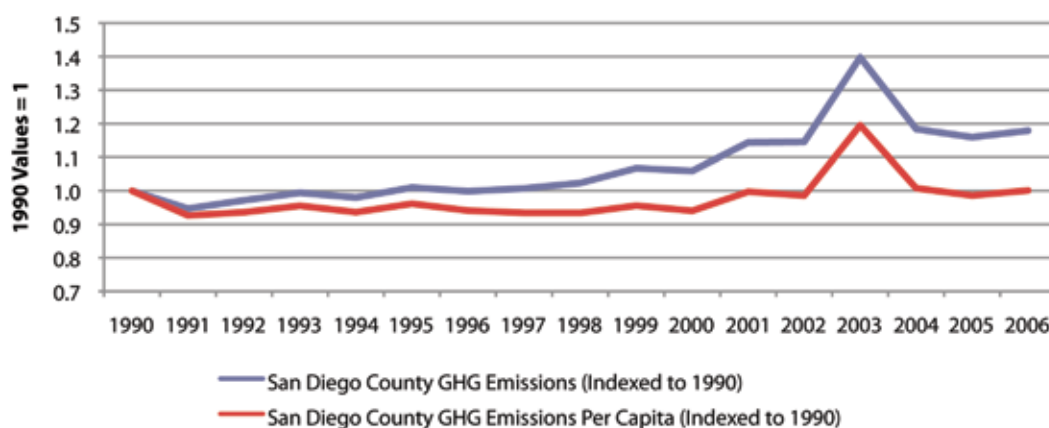
4. Data was not available to divide emissions from civil aviation and waste into economic sectors.





Per-capita emissions for the San Diego region was 12 metric tons of CO₂E in 2006 and has been basically flat since 1990; however, total emissions increased by 18%, as shown in Figure 4. It should be noted that while per-capita metrics are useful for comparing different geographical entities, total emissions is the most important metric, since the object of AB 32 and other similar polices is to reduce the absolute amount of greenhouse gases in the atmosphere.

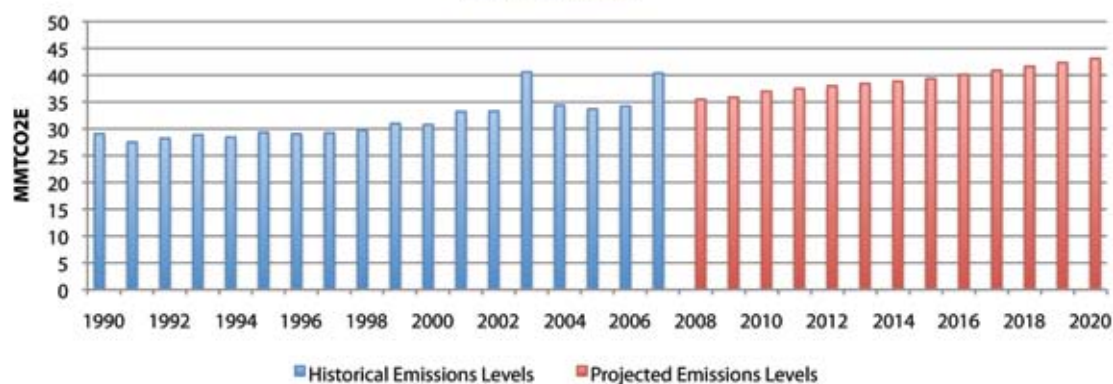
Figure 4. Comparison of Total and Per-Capita Emissions San Diego County



Emissions Projections

Given a business-as-usual trajectory, defined as no change in current trends or policies, greenhouse gas emissions from San Diego County will be approximately 43 MMT CO₂E in 2020, a 26% increase over 2006 levels and a 48% increase over 1990 levels. Figure 5 shows the projected emissions levels under the business-as-usual scenario.

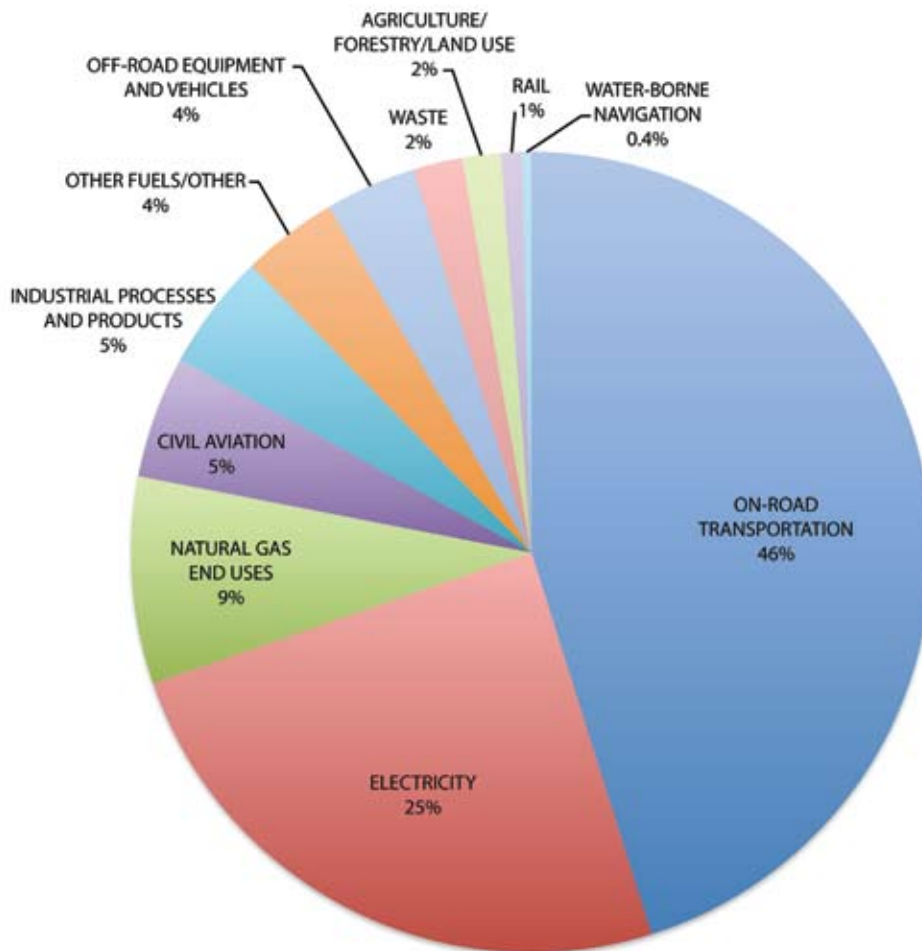
Figure 5. Total GHG Emissions for San Diego County (1990-2020)



Regional Greenhouse Gas Emissions by Category

While many different sources emit greenhouse gases in San Diego County, a few sources account for the vast majority of emissions in San Diego County. The on-road transportation category—comprising cars and trucks—is by far the largest contributor of greenhouse gas emissions in the region, accounting for 46% of the total, almost twice as much as the next largest sector. Electricity generation and natural gas combustion were the second (25%) and third (9%) highest emitting sectors. These top three categories emit 80% of total greenhouse gases in San Diego County. Civil aviation, mainly interstate flights from Lindbergh Field, is the fourth highest emitting category (5%). Given San Diego's economic make up, emissions associated with non-fuel industrial processes and product use (mainly refrigerants) are relatively small and represent just under 5% of emissions, slightly higher than the emissions from the other fuels/other category (4%), which includes the use of fuels such as propane, which are not captured in other categories of the inventory. Finally, off-road transportation and equipment activities, which include construction and mining equipment, pleasure boats, and some agricultural equipment, account for about 4% of the emissions.⁵ Figure 6 shows the breakdown of emissions by source. A detailed table of inventory results can be found on page 16 of this report. (Table 3)

Figure 6. San Diego County GHG Emissions by Category (2006)



5. Emissions from industrial activities involving fuel combustion are captured mainly in the electricity and natural gas categories.



Table 1 shows the emissions categories and subcategories included in the inventory.

Table 1. Emissions Inventory Categories

AGRICULTURE

Enteric Fermentation
Manure

CIVIL AVIATION

Interstate Flights
Intrastate Flights

ELECTRICITY

Residential
Commercial
Industrial
Mining
Agricultural
Telephone, communications, utilities (TCU)
Street Lighting

DEVELOPMENT

Loss of farmland
Loss of native vegetation

INDUSTRIAL PROCESSES AND PRODUCTS

HFC refrigerants
Sulfur hexafluoride
Other

NATURAL GAS END USES

Residential
Commercial
Industrial
Mining
Agricultural

OFF-ROAD EQUIPMENT AND VEHICLES

Construction and Mining Equipment
Pleasure Craft
Industrial Equipment
Agriculture Equipment
Other

ON-ROAD TRANSPORTATION

Passenger Vehicles
Light-Duty Trucks
Heavy-Duty Trucks and Vehicles
Motorcycle

OTHER FUELS/OTHER

Manufacturing
Transport
Residential
Commercial
Non-Specified
Agriculture
Cogeneration Thermal Emissions

RAIL TRANSPORTATION

SEQUESTRATION FROM LAND COVER

Forest growth
Woodland growth
Chaparral, scrub, and grasslands

WASTE

Landfills
Wastewater Treatment

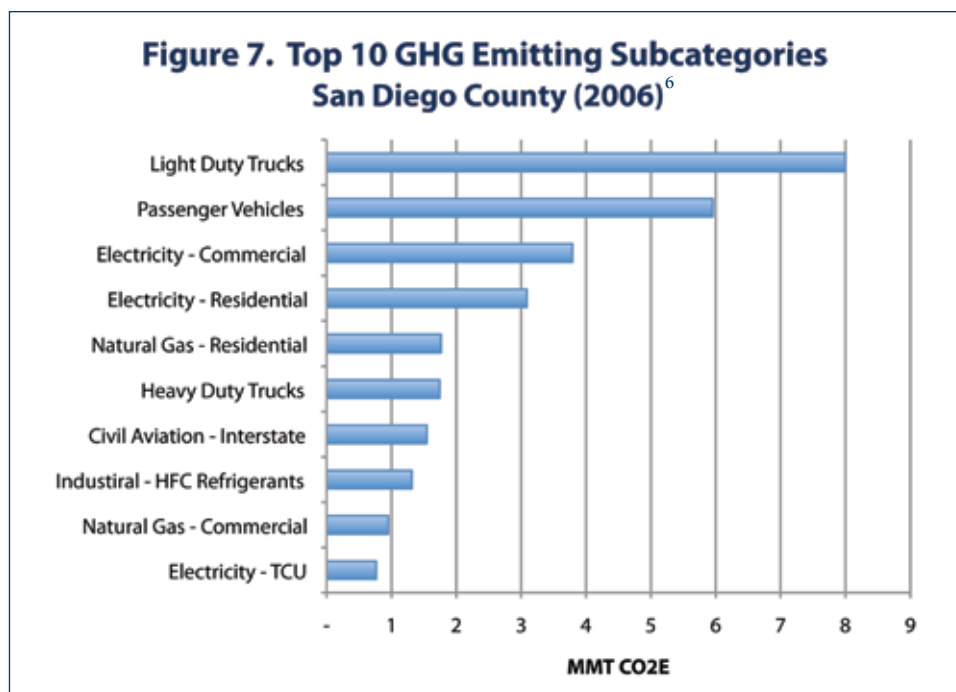
WATER-BORNE NAVIGATION

Ocean Going Vessels (OGV)
Harbor Craft

WILDFIRES

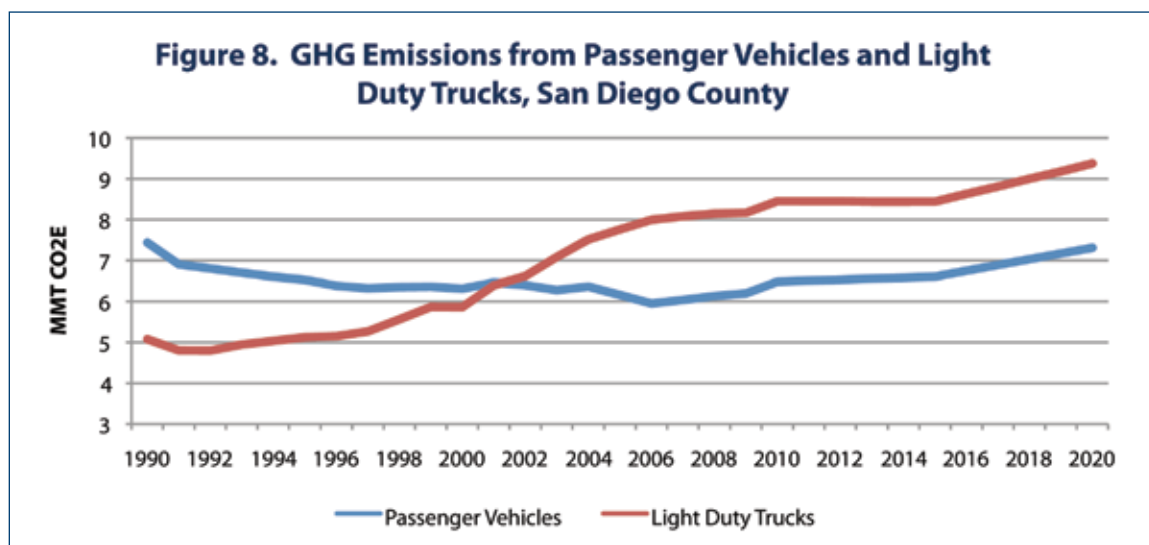
Forest
Woodlands
Chaparral, scrub, and grasslands

Figure 7 shows the top 10 emitting subcategories in San Diego County in 2006. Light-duty trucks and passenger vehicles are the highest emitting subcategories by a wide margin in all years. In 2003, the year of the devastating wildfires, emissions from all fires were the single largest source of greenhouse gases in the region that year, totaling 8 MMT CO₂E (20% of total emissions).



Emissions from Cars and Trucks

In 2006, light-duty trucks accounted for just over 50% of total on-road emissions, while passenger vehicles accounted for nearly 38%. Emissions from passenger vehicles were higher than those from light-duty trucks until 2003, when light-duty trucks became the highest emitting vehicle type in San Diego County (Figure 8). Figure 9 shows the on-road greenhouse gas emissions in 2006 by vehicle type.

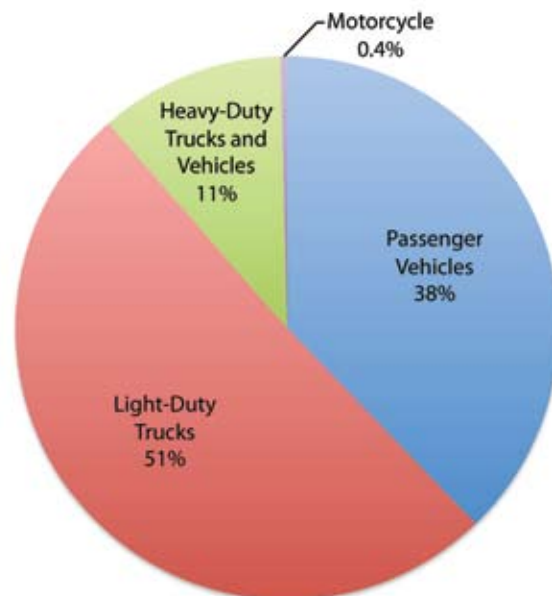


6. TCU is transportation, communication, and utilities.





Figure 9. On-Road Transportation GHG Emissions by Vehicle Type, San Diego County 2006

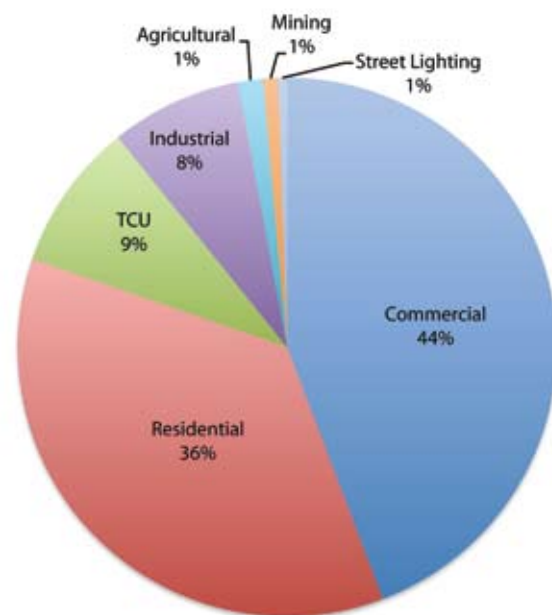


By 2020, greenhouse gas emissions from on-road vehicles are expected to reach 19 MMT CO₂E, a 21% increase over 2006 levels. Light-duty trucks are expected to continue to be the largest emitter among the vehicle classes representing nearly 50% of all emissions from the on-road transportation sector by 2020.

Emissions from Electricity Use

In 2006, electricity use accounted for 25% of total emissions in the region. About 44% of emissions from electricity came from consumption in the commercial sector. Residential sector consumption was close behind with 36%. Transportation, communication, and utilities (TCU) (9%) and the industrial sector (8%) are significantly lower than the leading subsectors. Figure 10 shows the relative breakdown of the electricity category.

Figure 10. Electricity Emissions by Subcategory San Diego County, 2006

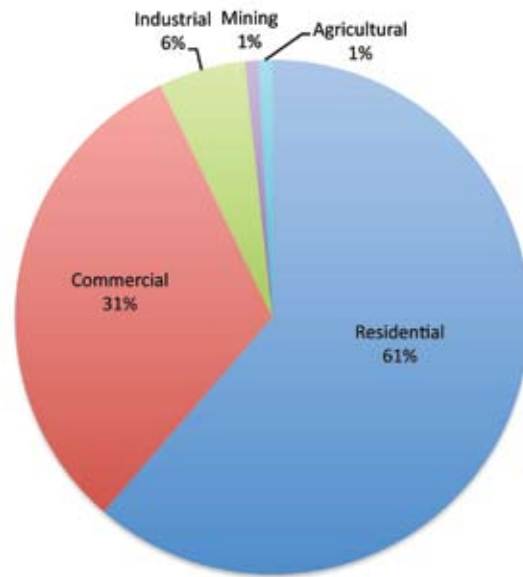


Emissions from electricity use increased by about 31% between 1990 and 2006, faster than population growth, and they are expected to increase by 28% over 2006 levels by 2020 under a business-as-usual scenario.

Emissions from Natural Gas End-use

Emissions from combustion of natural gas by end-users accounts for just under 9% of total greenhouse gas emissions in San Diego County. Of this total, the residential sector accounts for 60% of emissions, while the commercial sector emits about 33%. Figure 11 shows the contribution of each end-use sector to total natural gas emissions. Emissions associated with power generation from natural gas are accounted for in the electricity sector data.

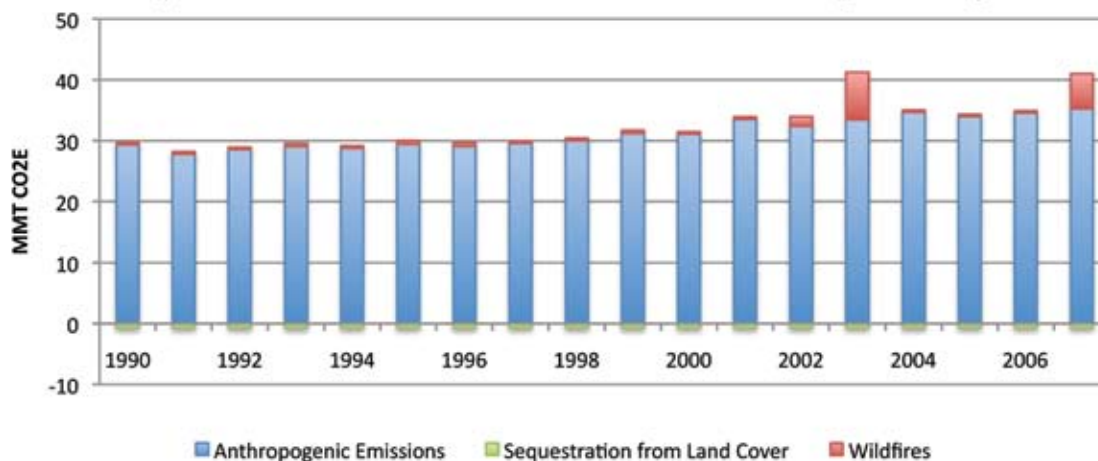
Figure 11. Natural Gas End Use Emissions By Sector, San Diego County 2006



Sequestration and Wildfires

In addition to the sources of emissions described above, this study estimated the ability of the vegetation in the county to absorb and sequester greenhouse gases. Carbon dioxide is taken up by growing plants and released again by decomposing plant matter displaced by development. During wildfires, the carbon dioxide stored in vegetation is released along with the other greenhouse gases nitrous oxide and methane. Figure 12 shows the total sources and sinks of greenhouse gas emissions for San Diego County from 1990 to 2008. The very small green bars at the bottom indicate the level of carbon dioxide sequestered by vegetation. By contrast, the red bars at the top indicate the amount of greenhouse gas emitted by wildfires. The 2003 firestorm released nearly 8 MMT CO₂E, more greenhouse gases than any other single emitting subcategory that year. These fires caused greenhouse gas emissions for that year to reach levels approximately equivalent to the projected emissions for 2017.

Figure 12. Total GHG Sources and Sinks San Diego County

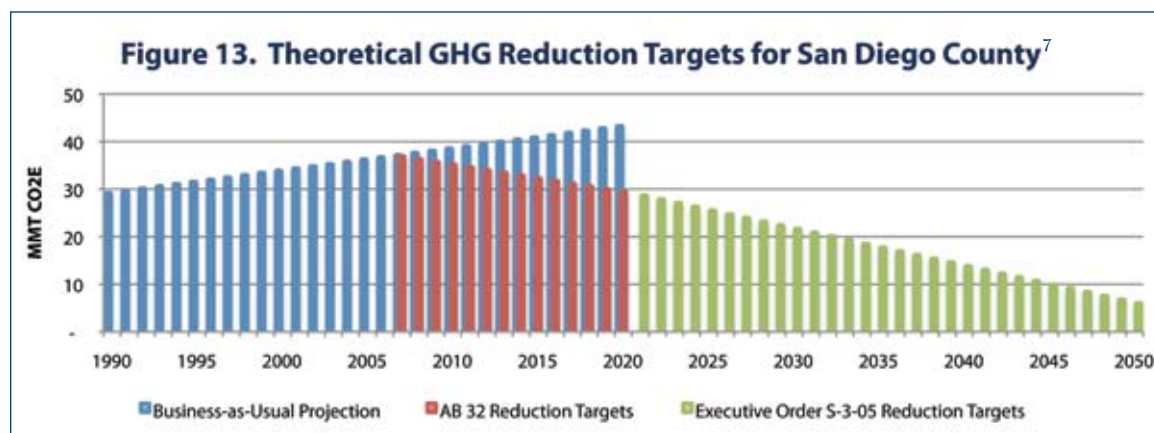




Emissions Reduction Targets

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide emissions to 1990 levels by the year 2020. While AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets for San Diego County. To meet the targets established by AB 32, the San Diego region would have to reduce its projected business-as-usual 2020 emissions by 14 MMT CO₂E or 33%.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for greenhouse gas emissions reductions to levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target of California regulations. Like AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, total emissions would have to be reduced to 6 MMT CO₂E, 37 MMT CO₂E (87%) below the 2020 business-as-usual projection and 28 MMT CO₂E (83%) below 2006 levels. Figure 13 illustrates the magnitude of the theoretical emissions reductions necessary if San Diego County were required to meet both AB 32 and Executive Order S-3-05 targets.



Reduction Strategies—Wedges

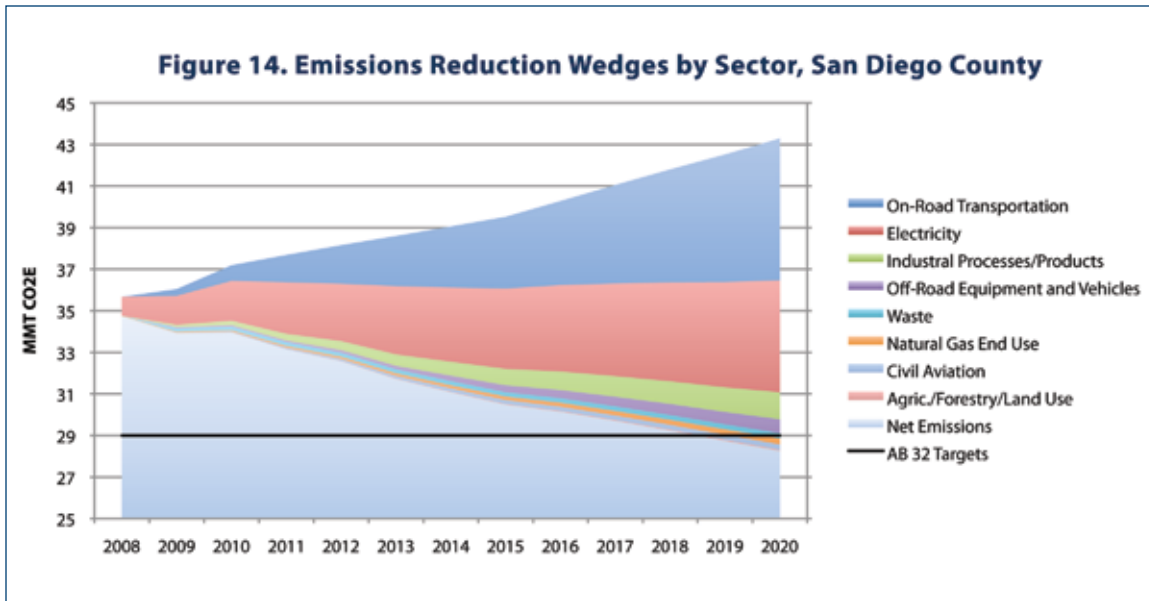
To illustrate how San Diego County could achieve the AB 32 targets and reduce emissions by 14 MMT CO₂E, the project team developed a range of strategies and calculated how much each could reduce emissions. The results were used to develop emissions reduction “wedges” illustrated in Figure 14 and Table 2. This approach was adapted from the well-known study by Pacala and Sokolow demonstrating that global emissions could be reduced to levels that would stabilize climate change using existing technologies.⁸ They took the total reductions needed to stabilize emissions and split that amount into equal parts, or wedges, each wedge representing an equal reduction.

This study followed a similar approach to demonstrate how San Diego County could reduce its greenhouse gas emissions to meet AB 32 targets. Instead of making equal wedges to achieve the reduction goals, the project team developed specific wedges

7. For simplicity, the business-as-usual projection is smoothed from 1990 to 2020.

8. S. Pacala and R. Sokolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*. Science 13 August 2004, Vol 305, pp. 968-972.

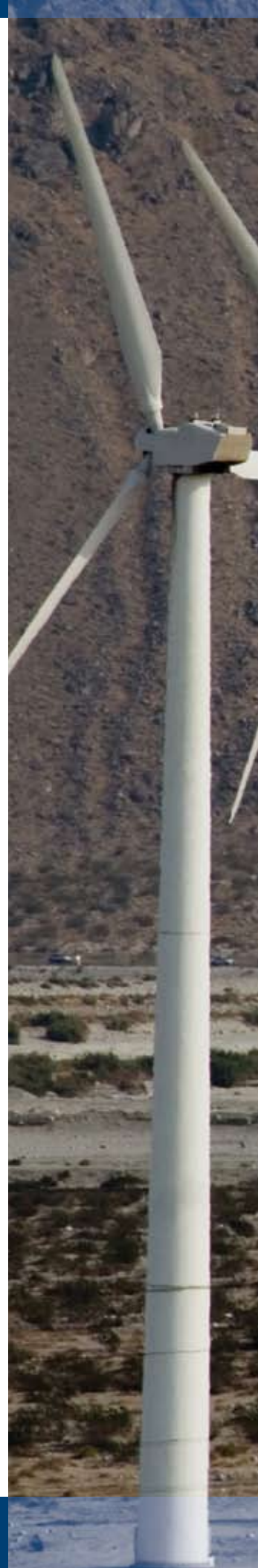
to show the effects of existing or expected policy changes. In most cases, wedges represent emissions reductions associated with existing law or regulation or are based on an authoritative source. In some cases, wedges were calculated on the basis of hypothetical but practical or realistic future policy changes. Figure 14 shows the relative greenhouse gas reduction possible from each major emissions category. The highest emitting categories also have the potential for the most emissions reduction. The on-road transportation and electricity categories account for 81% of total reductions: on-road transportation contributing 7 MMT CO₂E (45%) and electricity contributing 5 MMT CO₂E (36%) to the total. Some sectors have no emissions reduction wedge, due to their limited reduction potential.



The study identified 21 emissions reduction wedges and calculated how much each could reduce greenhouse gas emissions by 2020. Table 2 shows each wedge, its category, and the amount of emissions that it could reduce by 2020. The combined emissions reductions of these 21 wedges are 15 MMT CO₂E, slightly more than the 14 MMT CO₂E needed to reach AB 32 emissions targets prorated for San Diego County.

The largest reductions derive from state standards for renewable energy, vehicle tailpipe emissions, and clean fuels. California's tailpipe carbon dioxide regulations (Pavley) if fully implemented would account for 21% of total emissions reductions by 2020.⁹ It should be noted that the Pavley regulations would reduce emissions by just over 3 MMT CO₂E, significantly more than the new Federal corporate average fleet efficiency (CAFE) standards, adopted as part of the Federal energy legislation passed in 2007, which would reduce regional emissions by about 2 MMT CO₂E.

9. See AB 1493 (Pavley).



**Table 2. Emissions Reduction Wedges to Achieve AB 32**

CATEGORY	REDUCTION AMOUNT (MMT CO ₂ E)	PERCENTAGE OF TOTAL
ON-ROAD TRANSPORTATION	6.8	46%
2005 CAFE Standard	2.3	15%
Low-Carbon Fuel Standard	1.6	11%
Reduce Vehicle Miles Traveled by 10%	1.4	9%
Pavley Standard (Incremental to CAFE)*	0.9	6%
Light/Heavy Vehicle Efficiency/Hybridization	0.6	4%
ELECTRICITY	5.4	36%
Renewable Portfolio Standard 20%	2.0	13%
Reduce Electricity Consumption 10%	1.1	7%
Renewable Portfolio Standard 33% (Incremental)	1.0	7%
Cleaner Electricity Purchases (≤ 1100 lbs/MWh)	0.6	4%
Replace Boardman Contract	0.3	2%
California Solar Initiative 400 MW	0.2	1%
Increase CHP by 200 MW	0.2	1%
INDUSTRIAL PROCESSES AND PRODUCTS	1.3	9%
Phase out of HFCs	1.3	9%
OFF-ROAD EQUIPMENT AND VEHICLES	0.7	4%
Reduce Fuel Consumption by 15%	0.4	3%
Low-Carbon Fuel Standard	0.2	1%
Reduce Pleasure Craft Fuel Use by 35%	0.1	1%
NATURAL GAS END-USE	0.3	2%
Reduce Natural Gas Consumption 8%	0.3	2%
CIVIL AVIATION	0.3	2%
Civil Aviation Low-Carbon Fuel Standard	0.3	2%
WASTE	0.3	2%
Capture 80% of Landfill Gas	0.3	2%
AGRICULTURE/FORESTRY/LAND USE	0.05	0.3%
Urban Tree Planting / Preservation	0.02	0.1%
Tree Preservation during Development	0.03	0.2%
Total	15.0	100%

*The entire reduction attributable to Pavley is 3.2 MMT CO₂E (CAFE + Pavley).

Figure 15. Emissions Reduction Strategies for San Diego County to Meet Hypothetical AB 32 Targets by 2020

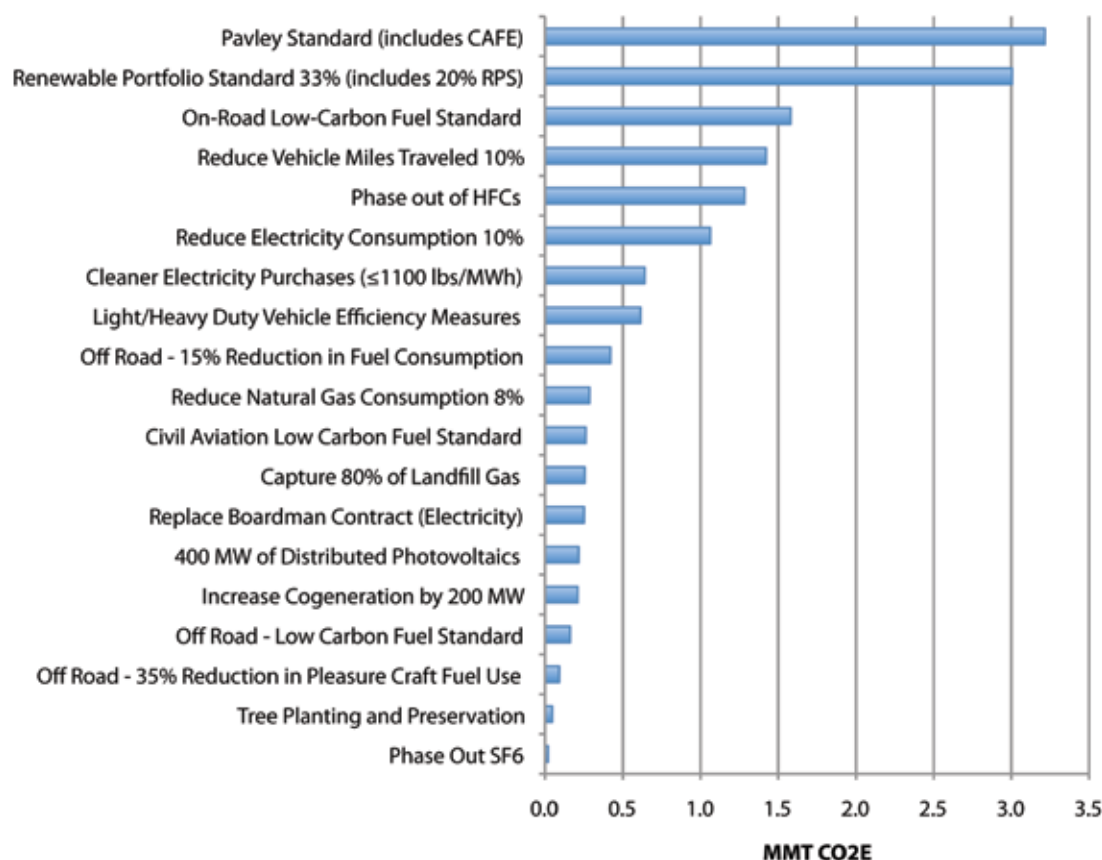


Figure 15 shows the magnitude of each individual emissions reduction wedge.


Emissions reductions from the Renewable Portfolio Standard (RPS) wedges account for 20% of total reductions. California's RPS requires the state's three investor-owned utilities to provide at least 20% of energy supplies from renewable sources by 2010.¹⁰

The emissions savings attributed to the 20% RPS wedge presented in Table 2 represents incremental renewable energy additions above levels already achieved by the local utility. In addition, the California Energy Commission's Integrated Energy Policy Report for 2007 recommends increasing the RPS to 33%.¹¹ While this increase to 33% is not law, it is very likely to be codified in the coming years. The wedge amount in Table 2 for the 33% RPS represents the incremental emissions reductions over the existing RPS requirements that would be achieved by increasing renewable energy supplies an additional 13%. A single amount for both the 20% and 33% RPS is presented in Figure 15.

The California Air Resources Board (CARB) has approved the Low-Carbon Fuel Standard as an early action measure for meeting AB 32 emissions reduction targets. This standard,

10. S. Pacala and R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*. Science 13 August 2004, Vol 305, pp. 968-972.

11. 007 Integrated Energy Policy Report, Commission Final Report, adopted December 5, 2007. Publication CEC-100-2007-008-CME. Available from the CEC at http://www.energy.ca.gov/2007_energy_policy/index.html.



which was promulgated in Executive Order S-01-07, would reduce the carbon intensity of transportation fuels sold in California by 10% by 2020.¹² Applying this standard to fuels used by on-road vehicles would reduce greenhouse gas emissions by 11%. Reduction in vehicle miles traveled and increased vehicle efficiency measures make up the final transportation wedges.

While many of the strategies identified here are based in state and federal law, there is a significant role for local governments in realizing emissions reductions. While local governments can help to facilitate statewide standards like the renewable portfolio standard, they can play a more direct role in locally and regionally based strategies. Strategies include reducing vehicle miles traveled, electricity and natural gas consumption, increasing use of distributed energy resources such as cogeneration and photovoltaics, and capturing more methane gas at our region's landfills.

Conclusion

San Diego County emitted 34 million MMT CO₂E in 2006—an 18% increase over 1990 levels. This increase is commensurate with the increase in county population and statewide trends over the same period. On-road transportation, mainly cars and light-duty trucks, was responsible for 16 MMT CO₂E in 2006, 46% of total greenhouse gas emissions in San Diego County for that year, and was by far the largest emitting category of the inventory. The electricity category emitted 7 MMT CO₂E (25%) and natural gas end-use emitted 3 MMT CO₂E (9%). These top three emitting categories are significantly associated with activities by individuals (e.g., driving and home electricity and natural gas use); thus nearly 60% of total regional emissions are associated with individual activities.

By 2020, under a business-as-usual scenario, regional greenhouse gas emissions are expected to be 43 MMT CO₂E, increase of 8.52 MMT CO₂E (26%) over 2006 levels. Even though AB 32 does not specify reduction targets for counties, to achieve its emissions reduction targets (1990 levels by 2020), San Diego County would have to reduce emissions by 14 MMT CO₂E (30%) below projected business-as-usual levels in 2020. San Diego County can reduce its greenhouse gas emissions to 1990 levels by 2020 through a combination of reductions strategies from all sectors, mainly driven by renewable energy mandates, fuel efficiency standards, and a low-carbon fuel standard. This study estimates that through a combination of 21 strategies, the region could reduce its emissions by 15 MMT CO₂E by 2020, slightly more than required to reach 1990 levels.

Clearly, meeting the greenhouse gas emissions targets of AB 32 targets will involve the entire state, and actions taken on a multi-county or regional basis may well influence the contributions made by or needed from San Diego County. A detailed analysis of the local and regional policy changes necessary to achieve the potential emissions reductions presented here was beyond the purview of this report, but will be addressed in the next phase of the project.

12. Go to <http://gov.ca.gov/index.php?/executive-order/5172/>

Table 3. San Diego County GHG Inventory and Emissions Projections (MMT CO₂E)

	Business-as-Usual Projections						
	1990	1995	2000	2005	2010	2015	2020
ON-ROAD TRANSPORTATION	14	13	14	16	17	17	19
Passenger Vehicles	7.4	6.5	6.3	6.2	6.5	6.6	7.3
Light-Duty Trucks	5.1	5.1	5.9	7.8	8.5	8.4	9.4
Heavy-Duty Trucks and Vehicles	1.8	1.6	1.7	1.9	1.9	2.0	2.3
Motorcycle	0.04	0.03	0.02	0.1	0.1	0.1	0.1
ELECTRICITY	6.5	7.2	8.0	8.3	9.4	10	11
Residential	2.4	2.6	2.7	2.9	3.4	3.6	3.9
Commercial	2.6	2.9	3.6	3.7	4.3	4.7	5.2
Industrial	0.7	0.7	0.8	0.7	0.7	0.7	0.7
Mining	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Agricultural	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TCU	0.6	0.7	0.7	0.7	0.8	0.9	0.9
Street Lighting	0.03	0.04	0.04	0.04	0.05	0.1	0.1
NATURAL GAS END USES	3.0	2.8	2.6	2.9	3.2	3.4	3.6
Residential	1.8	1.7	1.8	1.7	1.9	2.0	2.1
Commercial	0.7	0.7	0.5	0.9	1.0	1.1	1.2
Industrial	0.4	0.3	0.2	0.1	0.2	0.2	0.2
Mining	0.04	0.02	0.01	0.03	0.03	0.03	0.03
Agricultural	0.03	0.03	0.02	0.03	0.03	0.03	0.03
OFF-ROAD EQUIPMENT AND VEHICLES	1.0	1.0	1.2	1.3	1.4	1.5	1.6
Construction and Mining Equipment	0.4	0.5	0.6	0.6	0.7	0.7	0.8
Pleasure Craft	0.1	0.1	0.1	0.2	0.2	0.2	0.3
Industrial Equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Agriculture Equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other	0.2	0.2	0.3	0.3	0.3	0.3	0.4
CIVIL AVIATION	1	1	2	2	2	2	3
Interstate	1.0	1.1	1.4	1.7	1.8	1.9	2.1
Intrastate	0.2	0.2	0.2	0.2	0.2	0.2	0.2
WASTE	0.9	1.1	0.5	0.4	0.7	0.8	0.9
Landfills	0.3	0.5	0.2	0.2	0.4	0.5	0.6
Wastewater Treatment	0.6	0.6	0.3	0.1	0.2	0.2	0.2
INDUSTRIAL PROCESSES AND PRODUCTS	0.5	0.7	1.2	1.6	2.0	2.4	2.8
HFC Refrigerants	0.003	0.3	0.8	1.2	1.6	2.0	2.5
Sulfur Hexafluoride	0.2	0.1	0.1	0.1	0.05	0.03	0.02
Other	0.3	0.2	0.3	0.3	0.3	0.3	0.3
WATER-BORNE NAVIGATION	0.04	0.1	0.1	0.1	0.1	0.2	0.2
Ocean Going Vessels (OGV)	0.03	0.0	0.1	0.1	0.1	0.1	0.1
Harbor Craft	0.01	0.01	0.02	0.02	0.03	0.03	0.04
RAIL TRANSPORTATION	0.2	0.2	0.3	0.3	0.3	0.4	0.4
OTHER/OTHER FUELS	1.6	1.4	1.5	1.3	1.2	1.2	1.2
Manufacturing	0.7	0.5	0.7	0.6	0.7	0.7	0.7
Transport	0.2	0.1	0.04	0.1	0.1	0.1	0.1
Non-Specified	0.04	0.04	0.1	0.1	0.1	0.2	0.2
Residential	0.2	0.1	0.2	0.1	0.1	0.1	0.1
Energy	0.02	0.02	0.02	0.03	0.03	0.03	0.03
Commercial	0.3	0.2	0.2	0.1	0.1	0.05	0.02
Cogeneration Non-Electrical	0.2	0.4	0.4	0.3	n/a	n/a	n/a
AGRICULTURE (LIVESTOCK)	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Enteric Fermentation	0.1	0.1	0.05	0.04	0.03	0.02	0.02
Manure	0.1	0.1	0.04	0.03	0.02	0.02	0.01
WILDFIRES	0.2	0.6	0.2	0.3	0.3	0.3	0.3
Forest	0.03	0.01	0.05	0.03	0.03	0.03	0.03
Woodland	0.01	0.1	0.04	0.02	0.02	0.02	0.02
Chaparral, Scrub, and Grasslands	0.1	0.5	0.1	0.2	0.2	0.2	0.2
DEVELOPMENT (LOSS OF VEGETATION)	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Loss of Farmland	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Loss of Native Vegetation	0.02	0.03	0.2	0.2	0.2	0.2	0.2
SEQUESTRATION FROM LAND COVER	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
Forest	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Woodland Growth	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Chaparral, Scrub, and Grasslands	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
TOTAL	29	29	31	34	37	39	43



About the Energy Policy Initiatives Center (EPIC)

The Energy Policy Initiatives Center (EPIC) is a nonprofit academic and research center of the University of San Diego School of Law that studies energy policy issues affecting the San Diego region and California. EPIC integrates research and analysis, law school study and public education. The organization also serves as a source of legal and policy expertise and information in the development of sustainable solutions that meet our future energy needs.

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An aerial photograph of the San Diego coastline, showing a residential area with houses and trees, a beach, and a large bridge spanning a body of water. The bridge has multiple concrete piers and a blue-painted deck.

San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

On-Road Transportation Report

Sean Tanaka

Tanaka Research and Consulting

September 2008



An aerial photograph of San Diego, California, showing a coastal city with a mix of residential and commercial buildings. In the foreground, a large concrete bridge with multiple piers spans a body of water. The city extends to the beach and the ocean in the background.

On-Road Transportation Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

On-road transportation is a significant source of greenhouse gas (GHG) emissions. In San Diego County, emissions from on-road vehicles account for about 46% of regional GHG emissions. This report, a component of the San Diego County Greenhouse Gas Inventory project, provides an estimate of historical GHG emissions associated with on-road transportation from 1990 to 2006 and future emissions to 2020 for San Diego County. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for the region's on-road transportation sector. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) in order for San Diego County to reduce emissions to 1990 levels by 2020 – the statewide statutory target under AB 32. Finally, the report identifies and quantifies potential emissions reduction strategies to determine the feasibility of reducing on-road transportation related emissions to 1990 levels by 2020.

To the extent possible, the project team followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide GHG inventory. In some instances, when doing so could yield a more accurate or precise result, the project modified the CARB method.

This report, which is intended as an overview of the findings from research and analysis conducted for the on-road transportation sector, includes the following sections:

- Section 2 provides an overview of GHG emissions from on-road transportation in San Diego County, including total emissions, a breakdown of emissions by vehicle type (passenger car, light-duty truck, heavy-duty vehicles etc.), a summary of the highest emitting vehicle types and their respective characteristics and activities and projections to 2020.
- Section 3 discusses emissions reduction targets as well as strategies to reduce on-road transportation GHG emissions to 1990 levels by 2020.
- Section 4 provides a detailed discussion of the method used to estimate emissions for this category.

1.1. Key Findings

- On-road transportation is the largest greenhouse-gas-emitting category, with 16 MMT CO₂E in 2006, a 10% increase over 1990.
- Emissions from on-road vehicles are expected to increase to 19 MMT CO₂E by 2020, a 20% increase over 2006 levels and a 33% increase over 1990 levels.
- Passenger vehicles (cars and light-duty trucks) emit more greenhouse gases than the other vehicle classes in the on-road transportation category. In 2006, passenger vehicles emitted 14 MMT CO₂E, 89% of all greenhouse gas (GHG) emissions from the on-road transportation sector. Light-duty trucks include light- and medium-duty trucks and sport utility vehicles (SUVs), and these have become the greatest emitters. They accounted for 24% of San Diego County's total GHG emissions in 2006.
- A combination of emissions reduction measures, including vehicle efficiency, clean fuels, and reductions in vehicle miles traveled, can reduce GHG emissions from the on-road transportation sector to 1990 levels by 2020.

2. Emissions from the On-Road Transportation Category

The on-road transportation category is the single largest contributor of GHG emissions in San Diego County. In 2006, emissions from this category were 16 million metric tons of carbon dioxide equivalent (MMT CO₂E), which comprised approximately 46% of all GHG emissions produced in San Diego County (Figure 1). This category will likely continue to be the most dominant emitter through 2020, when its emissions are expected to reach 19 MMT CO₂E.

On-road transportation emissions are primarily the result of fuel combustion from motorized vehicles that travel San Diego County freeways, highways, streets, and roads. Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) are the main greenhouse gases that transportation vehicles emit. This section analyzes the emissions of these three gases; emissions due to refrigerant losses are accounted for in the industrial section.

The vehicle classes included in this analysis are passenger cars; light-, medium-, and heavy-duty trucks; buses; motor homes; and motorcycles. Table 1 lists examples of these types of vehicles. Medium-duty trucks have been included in the light-duty trucks category because their function is similar, primarily individual/personal transport.

Under a business-as-usual scenario (based on the San Diego Association of Governments (SANDAG) Regional Transportation Plan), annual emissions from this category are expected to increase to 19 MMT CO₂E by 2020, a 20% increase over 2006 levels. This scenario assumes that transportation growth and fuel consumption continue at the present rate with no major policy or behavioral changes.¹ Figure 2 shows the total emissions from all on-road vehicles from 1990 to 2005 and the forecast to 2020.

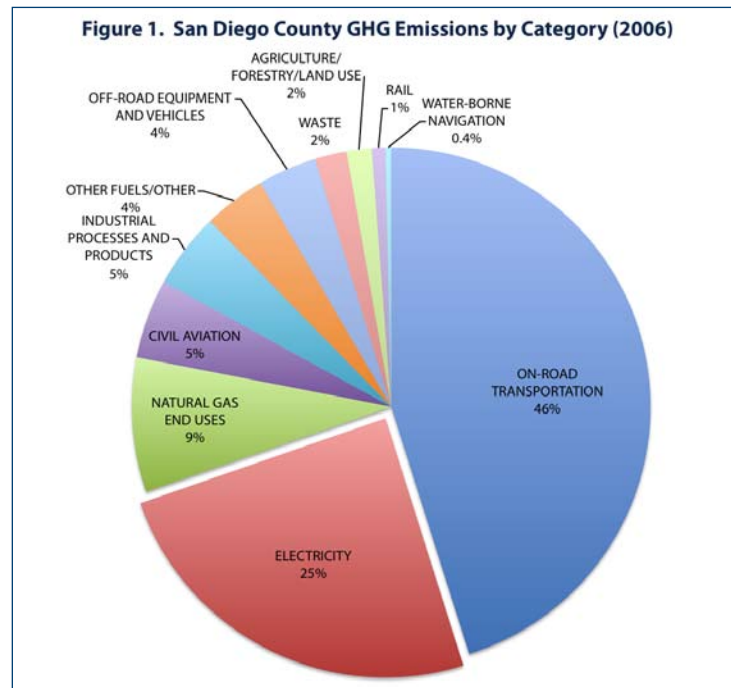
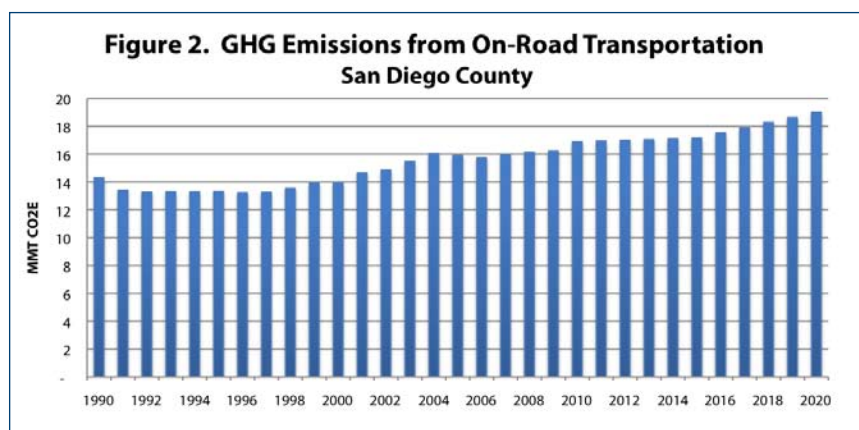


Table 1. San Diego County On-Road Transportation: Vehicle Class Examples

Vehicle Type	Example
Passenger car	Honda Accord, BMW 330, Chevy Impala, Chrysler 300
Light-duty truck	Ford Ranger and Explorer, Toyota Tacoma, GM full-size truck, SUV's
Heavy-duty truck	18 wheel trucks, large FedEx and U-haul trucks
Bus	Metropolitan Transit System (MTS) bus
Motorcycle	Suzuki Hayabusa, Harley Davidson Road King



Greenhouse gas emissions vary significantly among vehicle types. Figure 3 illustrates that passenger cars and light-duty trucks are currently the largest contributors of greenhouse gases. Together these two vehicle categories account for approximately 89% of emissions from the on-road transportation sector and 41% of all GHG emissions in the county.

The amount of GHG emitted by each vehicle type has varied over time. Between 1990 and 2001, passenger cars emitted the most; however, since 2002, light-duty trucks have surpassed passenger cars as the largest class of emitters. Figure 4 shows this trend.

Light-duty trucks are expected to continue to be the largest emitting vehicle class, representing nearly 50% of on-road emissions and nearly 22% of the county's 2020 total emissions (Figure 5). Passenger cars are projected to represent about 38% of on-road emissions by that same time.

The two main drivers of emissions in the on-road transportation category are total fuel consumption and vehicle miles traveled. Figure 6 shows fuel consumption by vehicle type. It demonstrates that passenger cars and light-duty trucks consistently consume over 85% of the fuel used by on-road vehicles. Combined fuel consumption from these two vehicle classes is expected to increase 21%, from 1.5 billion gallons in 2006 to more than 1.8 billion by 2020. Motorcycles consume the least amount of fuel, from 6.8 million gallons per year in 2006 to a forecast 10 million in 2020.

On the basis of business-as-usual projections, light-duty trucks will continue to be the largest fuel consumers through 2020. However, continued dramatic increases in fuel price may shift a large portion of light-duty truck

Figure 3. GHG Emissions from On-Road Vehicles, San Diego County (2006)

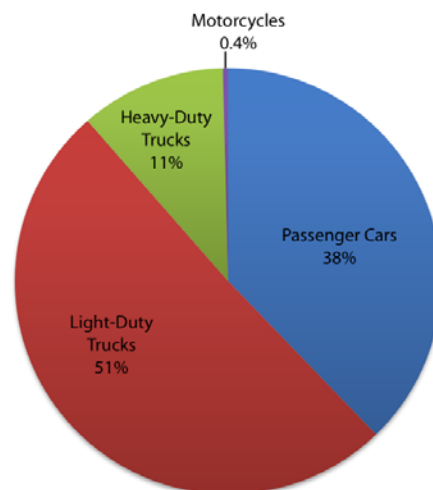


Figure 4. GHG Emissions from Passenger Cars and Light-Duty Trucks, San Diego County

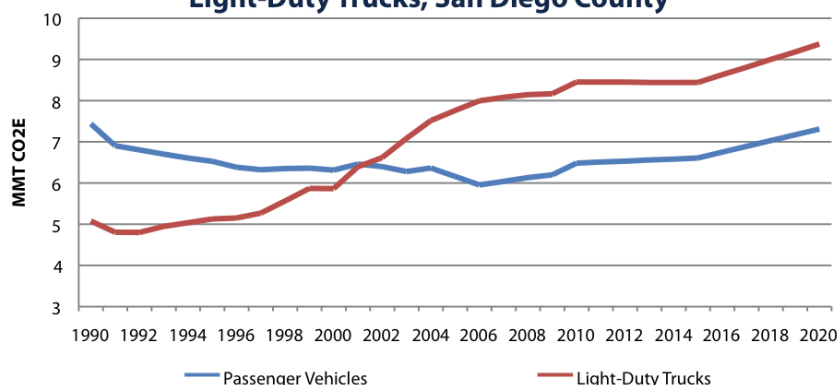
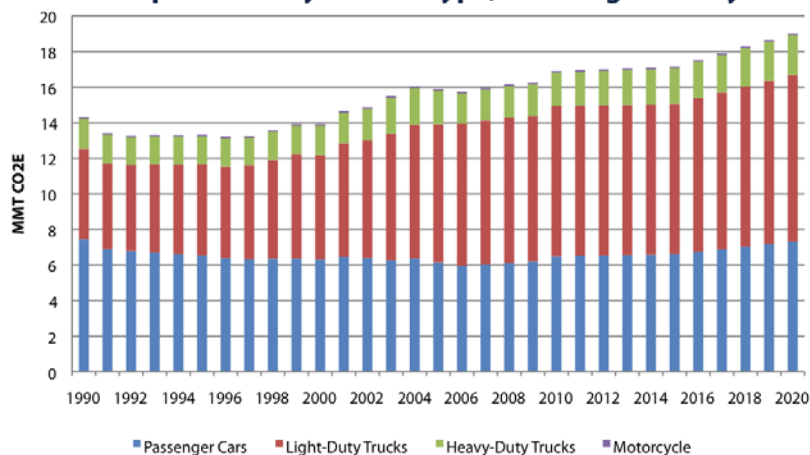


Figure 5. GHG Emissions from On-Road Transportation by Vehicle Type, San Diego County



use toward more fuel-efficient passenger car use. Heavy-duty truck fuel consumption is expected to increase steadily from 170 million gallons in 2006 to 220 million in 2020, nearly 30%.

The number of miles driven by a vehicle in a year is a strong factor in determining its emissions. In 1990, the total number of vehicle miles traveled was 22 billion. This number increased 31% to 30 billion by 2006. In 1990, passenger cars accounted for about 60% of total vehicle miles traveled, while light-duty trucks accounted for 35%. By 2006, these two vehicle classes each accounted for about 48% of overall miles traveled in San Diego County. The total number of miles driven by on-road vehicles annually in San Diego County is expected to increase another 31% to 37 billion miles by 2020, a 64% increase over 1990 levels. Figure 7 demonstrates the trend.

2.1. Emissions Reduction Targets

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), establishing statutory

limits on GHG emissions in California. AB 32 seeks to reduce statewide emissions to 1990 levels by the year 2020. Even though it does not specify reduction targets for specific areas or jurisdictions, this study calculated theoretical reductions targets proportionally for San Diego County. To meet the targets established by AB 32, San Diego would have to reduce projected on-road transportation emissions by 4.7 MMT CO₂E from 2006 levels to reach 1990 levels – a 24.7% reduction.

Earlier, in 2005, Governor Schwarzenegger signed Executive Order S-3-05, which established long-term targets for GHG emissions reductions to 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target toward which California regulations should aim. Like AB 32, Executive Order S-3-05 was intended to be a statewide target, but if applied hypothetically to San Diego County, total emissions from on-road transportation would have to be reduced to 2.9 MMT CO₂E – a reduction of nearly 16.1 MMT CO₂E below the 2020 business-as-usual forecast and 12.9 MMT CO₂E below 2006 levels.

Figure 6. Fuel Consumption by On-Road Transportation Vehicles in San Diego County

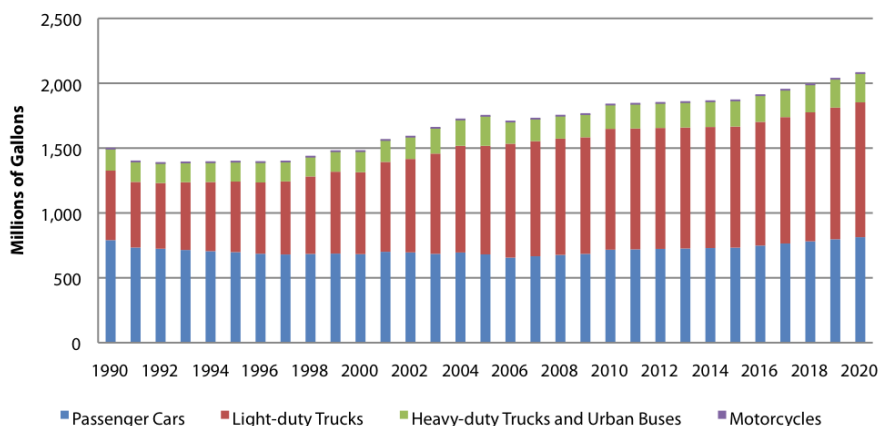


Figure 7. Vehicle Miles Traveled by On-Road Vehicles in San Diego County

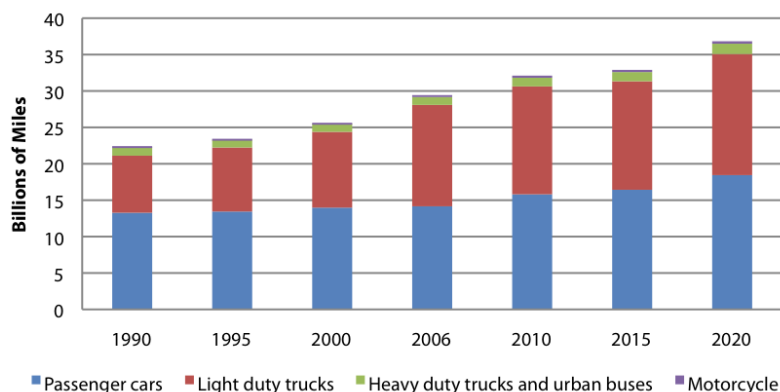


Figure 8 compares 2006 emissions levels, 2020 business-as-usual projections, AB 32, and Executive Order S-3-05 targets.

3. Emissions Reduction Strategies – Wedges

To illustrate how San Diego County could achieve AB 32 reduction targets for the on-road transportation category, the project team developed several emissions reductions strategies and calculated the “wedges” illustrated in Table 2 and Figure 9. This approach was adapted from the well-known study by Pacala and Socolow, who demonstrated that global emissions could be reduced to levels that would stabilize climate change with existing technologies.²

The project team developed five wedges to reduce GHG emissions from the on-road transportation category to 1990 levels. Each wedge relies on either existing statutes or policy directives currently under consideration addressing total fuel consumption, fuel type, and vehicle miles traveled (VMT). The wedges are also based on effects of the Corporate Average Fuel Economy (CAFE) standard included in Title 49 of the Energy Independence and Security Act of 2007;³ California’s AB 1493, which is also referred to as the “Pavley” bill⁴; the Low Carbon Fuel Standard (LCFS)⁵; a 10% VMT reduction; and several vehicle efficiency measures included in CARB’s Climate Change Draft Scoping Plan.⁶ Table 2 shows each wedge and the amount of emissions that it could reduce by 2020. The combined emissions reductions represented by these five wedges is 6.8 MMT CO₂E, about 45% of the total amount needed to reach the AB 32 targets for the entire region.

Figure 9 is a graphical representation of how each wedge reduces emissions from the business-as-usual projection.

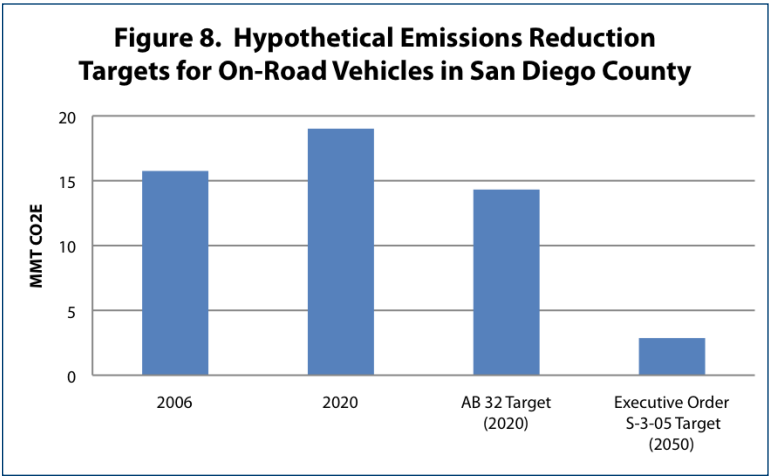
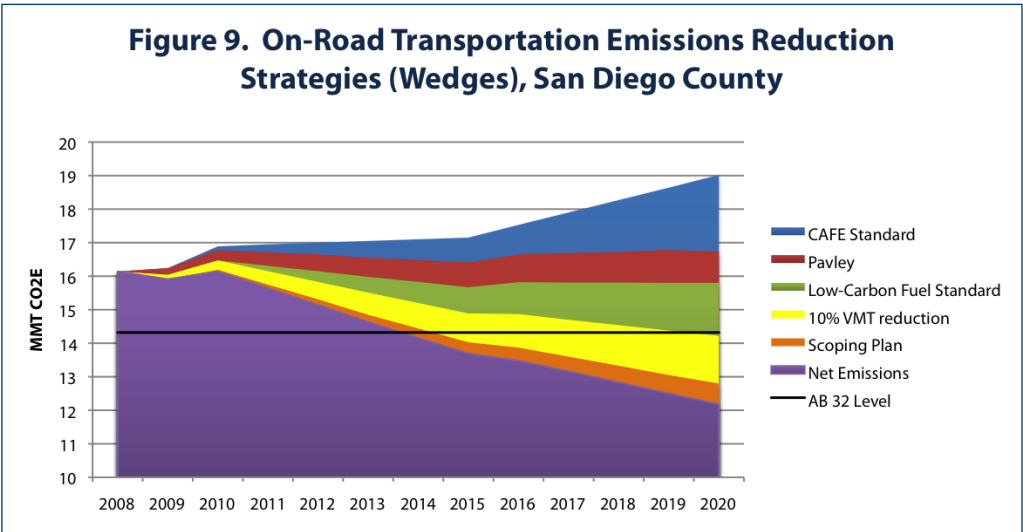


Table 2. Emissions Reduction Strategies for On-Road Transportation

Emissions Reduction Wedge	Emissions Reduction (MMT CO ₂ E)	% of Total Reduction
CAFE Standards	2.3	33%
Pavley (incremental increase over CAFE)*	0.9	14%
Low-Carbon Fuel Standard	1.6	23%
Reduce VMT by 10%	1.4	21%
Climate Change Scoping Plan	0.6	9%
Total	6.8	100%

*Total Pavely wedge is equal to 3.2 (CAFE + Pavley)



3.1. AB 1493 (Pavley 1 and 2)

AB 1493, or the Pavley Bill, is a standard for new light-duty passenger vehicles that could reduce San Diego County emissions from these vehicles by 21% by 2020.⁷ The law, which has not been implemented due to legal challenges, requires auto manufacturers to reduce vehicle emissions of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and hydrofluorocarbons (HFCs) in light-duty vehicles. AB 1493 defines light-duty passenger vehicles as including passenger cars, light-duty trucks, and medium-duty trucks/vehicles. Under the law, manufacturers would need to reduce greenhouse gases from tailpipe emissions and fugitive emissions from air-conditioning systems.

If implemented, the Pavley bill regulations would begin with the 2009 model year and end in 2016, when an 11% reduction in emissions is required. The period from 2009 to 2016 is known as “Pavley 1”; the period from 2017 to 2020 is “Pavley 2” and would require a 20% GHG reduction by 2020. Pavley 2 is a commitment made by the California Air Resources Board to extend progress from Pavley 1 and to increase the greenhouse gas reduction requirement to 20%.

3.2. Federal Corporate Average Fuel Economy (CAFE) Standards

The federal Corporate Average Fuel Economy (CAFE) standard determines the fuel efficiency of certain vehicle classes in the United States. The current standard has remained largely unchanged since 1990. In 2007, as part of the Energy and Security Act of 2007, CAFE standards were increased for new light-duty vehicles to 35 miles per gallon by 2020.⁸ The new CAFE standards will take effect no sooner than 2011, which was the start date used in this analysis. Unlike the Pavley Bill, which has a specific GHG emissions reduction target, the CAFE standards simply prescribe fuel economy, which will also result in greenhouse gas reductions.

In a study comparing Pavley 1 and 2 with the federal CAFE standard, CARB reported that the CAFE standard would reduce GHG emissions by 5% by 2016 and 12% by 2020⁹; the Pavley 1 and 2 standards are expected to reduce emissions by 20 % by 2020. The CAFE standard requires reductions from light- and heavy-duty vehicles, whereas Pavley 1 and 2 only require reductions from light-duty vehicles. A reduction requirement for heavy-duty vehicles has not yet been determined for CAFE; therefore, for purposes of this study, the emissions reduction requirement for heavy-duty vehicles is taken to be the same as the Federal standard for light-duty vehicles on a percentage basis, which is 5% by 2016 and 12% by 2020. Even though the effects of the Pavley Bill are greater than the effects of the new CAFE standards for light-duty vehicles, we chose to calculate separate values for each; however, the reader should note that the combined values presented for CAFE and Pavley are equivalent to the effects of Pavley regarding light-duty vehicles because we show only the incremental increase of Pavley over the CAFE standard.¹⁰

3.3. Low Carbon Fuel Standard (LCFS)

The Low Carbon Fuel Standard (LCFS) was included in a California Governor's Executive Order that was promulgated in January 2007. This strategy addresses the type of fuel used in vehicles. Efficiency standards affect the total amount of fuel used, whereas the low-carbon fuel standard seeks to reduce the carbon content of the fuel, therefore reducing GHG emissions even if total fuel consumption is not reduced. The Low-Carbon Fuel Standard has been approved by CARB as a discrete early action item under AB 32 and implementing regulations are currently under development. Because regulations have not been finalized, for the purposes of this study it was reasonable to assume that the effects of the Low-Carbon Fuel Standard would be a 10% reduction in GHG emissions from fuel use by 2020.

3.4. 10% Reduction in Vehicle Miles Traveled (VMT)

Vehicle miles traveled (VMT) is the third significant driver of emissions. No standard exists to regulate the number of miles driven, but reducing the total number of miles driven by 2020 can significantly reduce GHG emissions. The project team calculated the effects of a 10% reduction of vehicle miles traveled. This reduction is based in part upon the April 2008 Department of Transportation, Federal Highway Administration, “Traffic Volume Trends April 2008” report, which states “cumulative travel for 2008 decreased by 2.1 percent.” This decrease in VMT is only for the first quarter of 2008¹¹; therefore, it seemed both conservative and reasonable to extrapolate to a 10% reduction of VMT by 2020.

Although the link between vehicle miles traveled and increasing fuel prices is unclear, the report from the Federal Highway Administration indicates that this is the largest downward trend in 25 years.¹² And although predicting fuel prices is complex and beyond the scope of this project, it is likely that fuel prices will be higher in 2020 than they are today, therefore putting downward pressure on vehicle miles traveled.

3.5. Climate Change Scoping Plan: Reduction (Measures 9 and 11)¹³

The Climate Change Scoping Plan is a comprehensive plan that has been developed by the CARB to achieve the goals of AB 32, the Global Warming Solutions Act of 2006. Included in the Scoping Plan are strategies to reduce emissions by increasing efficiency, optimizing aerodynamics, and converting combustion-only vehicles to hybrids. Although these on-road emissions reduction measures are intended for implementation at the state level, several on-road transportation strategies in this plan were scaled down to San Diego County using data related to CO₂E emissions, vehicle population, and vehicle type. When scaled down, the CARB’s transportation efficiency, aerodynamics, and hybrid conversion strategies translate to an emissions reduction of 0.6 MMT CO₂E for San Diego County by 2020.

The measures in the Scoping Plan are a combination of strategies targeting light-, medium-, and heavy-duty vehicles. The county’s 2020 emissions reduction target for light-duty vehicles is 0.47 MMT CO₂E, which is to be accomplished by improving vehicle efficiency. The county’s heavy- and medium-duty vehicle target in relationship to this plan is a 0.14 MMT CO₂E reduction, achieved by optimized aerodynamics and hybridization.

4. On-Road Transportation Methodology

The on-road transportation methodology includes analysis of most motorized vehicles that travel San Diego County freeways, highways, streets, and roads. The vehicle types analyzed include: passenger cars; light-, medium-, and heavy-duty trucks; buses; motor homes; and motorcycles. The GHG gases that were analyzed include carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄). These gases comprise the majority of GHG gases emitted due to combustion from on-road vehicles.

4.1. Computation, Process, and Data

The on-road transportation GHG emissions were computed in two steps. First, by obtaining San Diego County on-road GHG emission data using the CARB on-road emissions modeling tool, Emissions FAcT or EMFAC. Second, further computations were conducted that followed the computational methodology used by CARB to develop their California GHG emissions inventory.¹⁴

EMFAC uses emissions rate and vehicle activity data to compute on-road vehicle emissions. Development of the data is based on variables such as vehicle population and age, vehicle type and weight, fuel type and consumption, vehicle miles traveled (VMT), vehicle technology, and emissions reduction technology.

In addition to the first step of using outputs for CO₂ and CH₄ from EMFAC, total hydrocarbons (THC), nitrogen oxides (NO_x), carbon monoxide (CO), molecular weight ratios, fuel consumption, and mass-balance methods were used to compute the final output of the major GHG gases (CO₂, N₂O, and CH₄) from on-road vehicles. This final computation is similar to the methodology used by CARB to develop its 2007 California GHG Emissions Inventory.¹⁵ When the GHG emissions inventory methodology for California was not applicable or did not make sense on a county scale, the CARB methodology was modified to apply to San Diego County. The main difference between the CARB computations and this study is the ratio of Federal Highway Administration fuel sales to the EMFAC computational fuel consumption for California. This ratio was not pertinent to San Diego County and computations were modified accordingly.

The EMFAC emissions output is generated in tons per day. This daily emissions rate was converted to an annual emissions rate based on the vehicle type (noncommercial or commercial). Noncommercial vehicle annual emissions were calculated on the basis of 347 effective days per year and included passenger cars, light-duty trucks, and motorcycles. Commercial vehicles included heavy-duty trucks and buses and their annual output was calculated on the basis of 327 effective days per year, on the assumption that vehicle activity and miles traveled decrease on weekends. GHG emissions from buses and motor homes were also included in this inventory. Owing to their similar gross vehicle weights, their respective emissions were included in the heavy-duty truck category.

4.2. Historical Emissions and Forecasts

Emissions from 1990 to 2005 were computed by Tanaka Research and Consulting using the method described in section 4.1. Forecasts from 2006 to 2020 used the same methodology described for 1990 to 2005, but the EMFAC inputs were provided by the SANDAG Transportation Division and were based on the Regional Transportation Plan. The final computation used the same methodology as the 1990 to 2005 time frame.

4.3. Wedge Configuration and Scenario Development

The project team calculated the following three wedge scenarios using the five wedges described above to assess whether and by how much the order in which the wedges were subtracted from the business-as-usual projection affected the total reductions:

1. Business-as-usual (BAU) case reduced by Pavley 1 and 2, CAFE, LCFS, a 10% VMT reduction and Climate Change Scoping Plan reduction
2. BAU reduced by CAFE, LCFS, 10% VMT reduction and Climate Change Scoping Plan reduction
3. BAU reduced by CAFE, 10% VMT reduction and Climate Change Scoping Plan reduction.

To calculate the effect of the emissions reductions included in each wedge, the project team subtracted the first wedge from the business-as-usual scenario. The second wedge was subtracted from the result of the first calculation (wedge), and so on. The order in which the wedges are calculated affects the net emissions after all the wedges are subtracted. Table 3 shows the results of the calculation for six scenarios, each using a different order. The project team chose to calculate wedges based on order 1 because its net emissions was closest to the 2020 net emissions average of the six possible reduction orders in Table 3. Also, since implementation of the tailpipe emissions standards included in the Pavley Bill has been delayed by litigation and Federal inaction, the project team thought it was reasonable to make the Federal CAFE standard the first wedge, since it is already law.

**Table 3. San Diego County On-Road Transportation:
Scenarios of Potential Reduction Strategy Order and Net Emissions**

Year	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6
	Net emission= BAU-CAFE- Pavley- LCFS-10% VMT Reduction- Scoping Plan	Net emission= BAU-CAFE- LCFS- Pavley- 10% VMT Reduction- Scoping Plan	Net emission= BAU- Pavley- CAFE- LCFS- 10% VMT Reduction- Scoping Plan	Net emission= BAU- Pavley- LCFS- CAFE- 10% VMT Reduction- Scoping Plan	Net Emission= BAU-LCFS- CAFE- Pavley- 10% VMT Reduction- Scoping Plan	Net emission= BAU-LCFS- Pavley- CAFE-10% VMT Reduction- Scoping Plan
1990	14.3	14.3	14.3	14.3	14.3	14.3
1995	13.3	13.3	13.3	13.3	13.3	13.3
2000	13.9	13.9	13.9	13.9	13.9	13.9
2005	15.9	15.9	15.9	15.9	15.9	15.9
2010	16.1	16.1	16.1	16.1	16.1	16.1
2015	13.7	13.7	13.6	13.6	13.8	13.7
2020	12.2	13.0	11.9	11.9	12.4	12.1

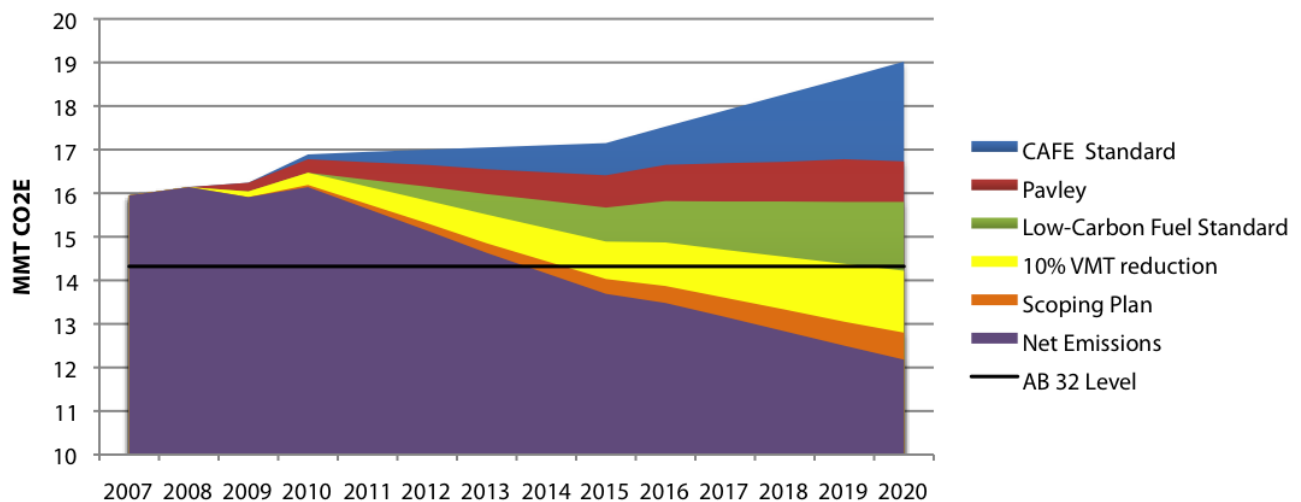
Wedge scenarios 1, 2, and 3 illustrate the significance of implementing the five wedges (CAFE, Pavley, LCFS, Climate Change Scoping Plan, and a 10% VMT reduction). A wedge summary is given in Table 4.

Table 4. Summary of Wedge Scenario Descriptions and GHG Reductions, San Diego County On-Road Transportation

Wedge Scenario	Wedges Included	2020 Net GHG Emissions after Application of Wedge Scenario (MMT CO ₂ E)	Additional Emissions Reductions Required to Meet AB 32 Targets (MMT CO ₂ E)
Wedge Scenario 1	BAU-CAFE-Pavley-LCFS - 10% VMT- Scoping Plan	12.2	-2.1 (meets and exceeds AB 32 target)
Wedge Scenario 2	BAU-CAFE-LCFS- 10% VMT- Scoping Plan	12.9	-1.4 (meets and exceeds AB 32 target)
Wedge Scenario 3	BAU-CAFE-10% VMT- Scoping Plan	14.5	0.2

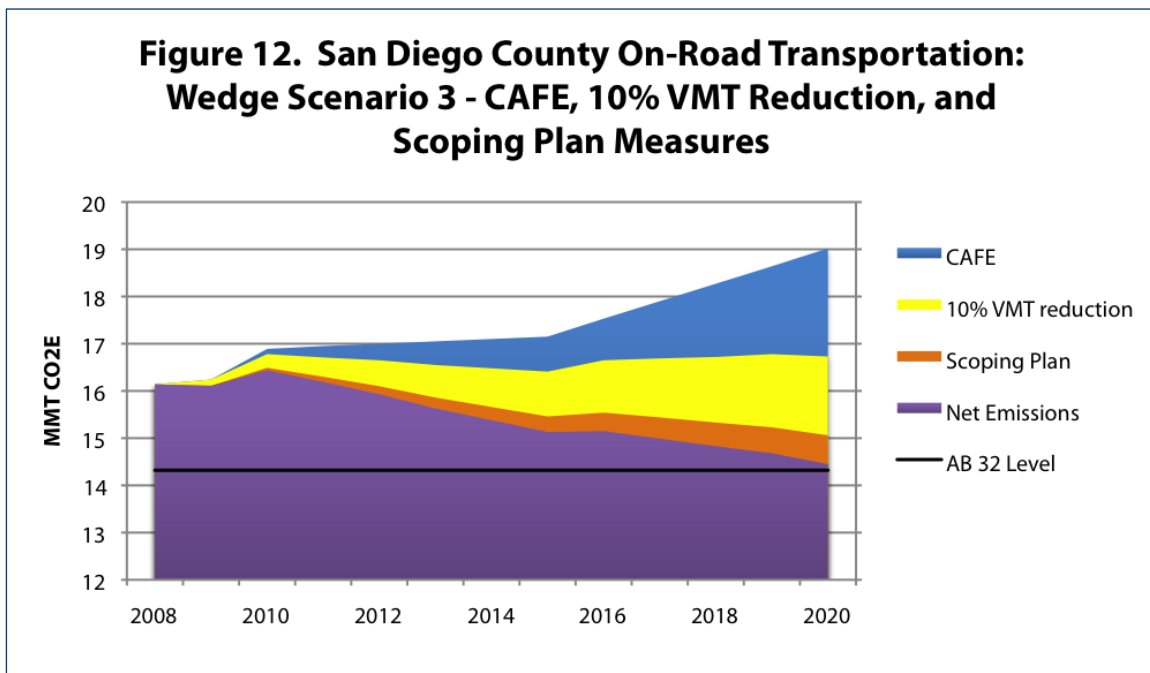
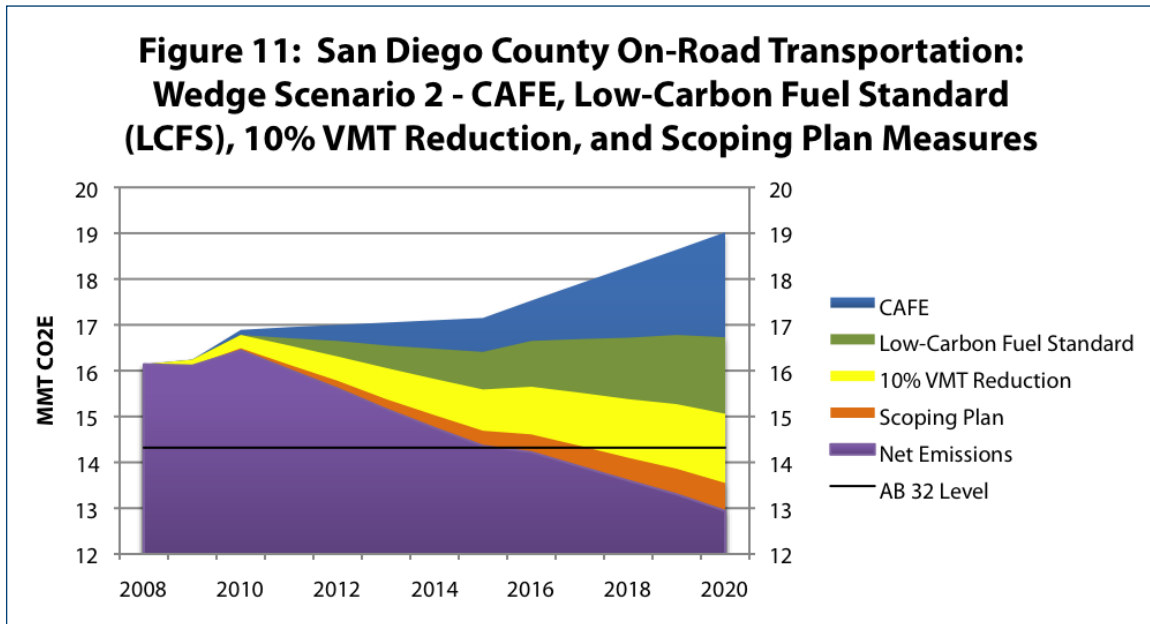
Wedge scenario 1 is the most comprehensive of the three wedge scenarios; it incorporates all five reduction strategies: CAFE, Pavley, LCFS, 10% VMT reduction, and Scoping Plan. This scenario is one of two that were able to meet/exceed the AB 32 target by reducing 2020 GHG emissions to 1990 levels. This shows the importance of all five reduction strategies. Scenario 1 has a net GHG emissions of 12.2 MMT CO₂E, which is 1.8 MMT CO₂E below the AB 32 requirement of 14.3 MMT CO₂E. The results of scenario 1 are displayed in Figure 10.

Figure 10. San Diego County On-Road Transportation: Wedge Scenario 1 - CAFE, Pavley 1 and 2, Low-Carbon Fuel Standard, 10% VMT Reduction, and Scoping Plan



Wedge scenario 2 is similar to scenario 1, but does not include Pavley 1 and 2, and has net emissions of 13.3 MMT CO₂E in 2020, which is 1 MMT CO₂E below the AB 32 target of 14 MMT CO₂E. The results of scenario 2 are displayed in Figure 11.

Wedge scenario 3 includes the CAFE reduction strategy, the 10% VMT reduction and the Scoping Plan (Figure 12). This scenario did not meet the AB 32 target of 14.32 MMT CO₂E. This scenario has a net emissions of 14.9 MMT CO₂E in 2020, which is 0.6 MMT CO₂E short of reaching the AB 32 target.



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San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

Natural Gas End-use Report

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September 2008





Natural Gas End-use Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

Natural gas consumption other than that used for electricity production is a significant source of greenhouse gas emissions (GHG).¹ In San Diego County, emissions from natural gas end uses, such as space and water heating, account for about 9% of regional GHG emissions. This report, a component of the San Diego County Greenhouse Gas Inventory project, provides an estimate of historical GHG emissions associated with natural gas end uses from 1990 to 2006 and future emissions to 2020 for San Diego County. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for the region's electricity sector. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to reduce emissions to 1990 levels by 2020 – the statewide statutory target under AB 32. Finally, the report identifies and quantifies potential emissions reduction strategies to determine the feasibility of reducing electricity-related emissions to 1990 levels by 2020.

This report, which is intended as an overview of the findings from research and analysis conducted for the natural gas end-use category, includes the following sections.

- Section 2 provides an overview of GHG emissions for natural gas end-use in San Diego County, including total emissions, a breakdown of emissions by subcategory (residential, commercial, etc.), a summary of the highest emitting commercial building types and activities, projections to 2020, and reduction targets.
- Section 3 discusses the strategies necessary to reduce natural gas end-use related emissions to 1990 levels by 2020.
- Section 4 provides a detailed discussion of the method used to estimate emissions for this category.

1.1. Key Findings for the Natural Gas End Uses Sector

The key findings of the report are summarized below.

- In 2006, greenhouse gas (GHG) emissions from natural gas end-use consumption were 3 MMT CO₂E, slightly lower than 1990 levels. This is due mainly to a significant decline in industrial consumption and basically flat residential consumption during this period.
- On the basis of a business-as-usual projection, emissions from natural gas end-use consumption are expected to increase by 0.6 MMT CO₂E (22%) between 2006 and 2020.
- To meet AB 32 reduction targets (1990 levels by 2020), emissions from natural gas end-uses will have to be reduced by 0.6 MMT CO₂E (16%) below projected 2020 levels.
- On average between 1990 and 2006, the residential sector accounted for 60% of total natural gas end-use consumption.
- It appears that it will be difficult to reduce emissions from natural gas consumption to 1990 levels by 2020 to reach AB 32 targets, though significant reductions are possible.

2. Emissions from Natural Gas End Uses

Combustion of natural gas results in release of greenhouse gases (GHG) into the atmosphere. Natural gas consumption for purposes other than electricity production is a relatively small, but still significant contributor to greenhouse gas emissions in San Diego County. In the county, natural gas end uses, including commercial, industrial, and residential consumption, represent 9% of total GHG emissions.² This sector ranks third in total regional emissions. Figure 1 shows the relative contributions of all categories to the region's GHG emissions.

Greenhouse gas emissions from natural gas end-use consumption were nearly 3 MMT CO₂E in 2006, essentially equal to consumption levels in 1990. This flat trend is due in part to a significant reduction and then leveling off of natural gas consumption in the industrial sector as well as limited growth in residential consumption. On the basis of available data, GHG emissions from natural gas end uses exceeded 1990 levels for the first time in 2007 and are expected to reach 4 MMT CO₂E by 2020, an increase of 22% above 2006 levels. Figure 2 presents historical and future projected trends in GHG emissions from the natural gas end-use category.

Figure 3 presents a comparison of population and emissions from natural gas, indexing both to 1990 levels. The data show that natural gas consumption has remained basically flat on average as regional population has increased by 18% since 1990.

Figure 1. San Diego County GHG Emissions by Category (2006)

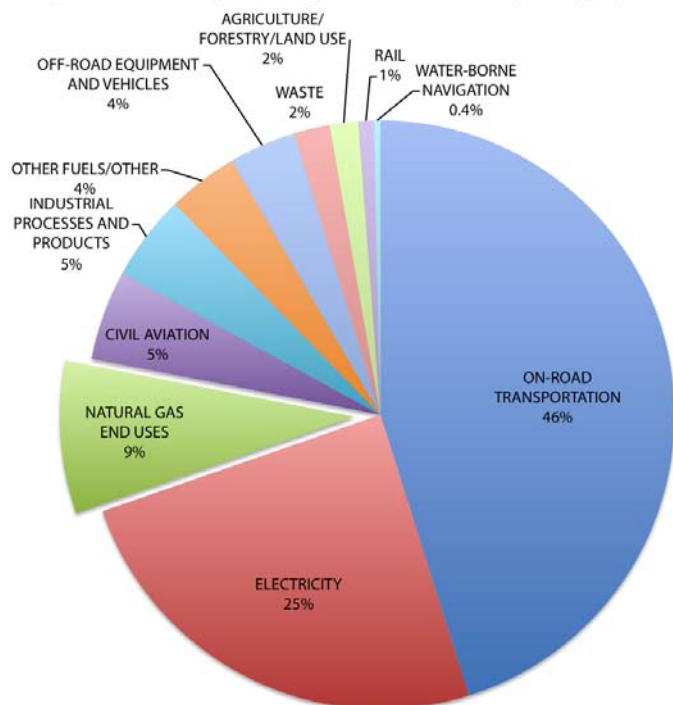


Figure 2. Emissions From Natural Gas End Uses San Diego County

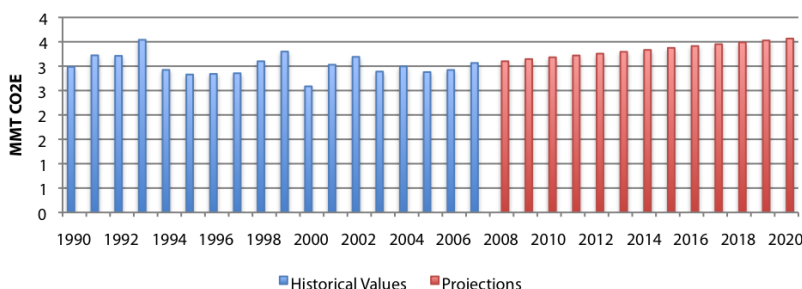
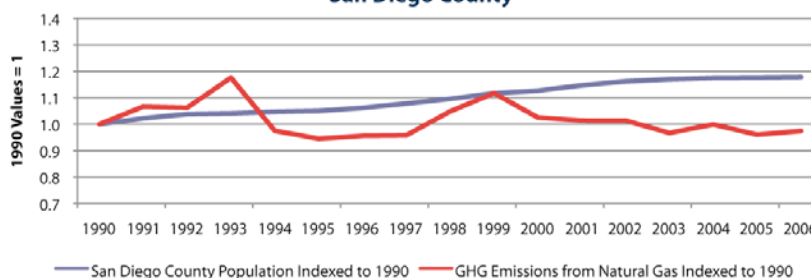


Figure 3. Population and Natural Gas Emissions San Diego County



Emissions from natural gas use correlate to consumption, since emissions estimates are derived directly from fuel use. The residential sector is the largest consumer of natural gas in the region, accounting for about 60% of total consumption and therefore GHG emissions from this category. Within the residential sector the largest uses of natural gas are space heating, water heating, clothes dryers, stoves and ovens, and pool heating.³ Figure 4 shows historical GHG emissions from natural gas end-use consumption through 2007 and projected consumption through 2020 by sector.^{4,5}

Commercial customers account for about 25% of total natural gas consumption and a commensurate level of GHG emissions in the region. Within the commercial sector, buildings consume approximately 30% of total natural gas. Figure 5 shows the natural gas consumption levels for commercial building types in 2006. Industrial end uses account for only about 5% of total natural gas consumption in San Diego County. Figure 6 shows the industrial categories consuming the most natural gas in 2006.

2.1. Emissions Reduction Targets

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide GHG emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific emissions

categories or jurisdictions, this study team calculated theoretical reductions targets as if the statewide statutory emissions reductions targets applied pro rata to San Diego County. This calculation included the necessary reductions for each emissions category, including natural gas. As demonstrated above, emissions

Figure 4. GHG Emissions from Natural Gas End Use in San Diego County⁶

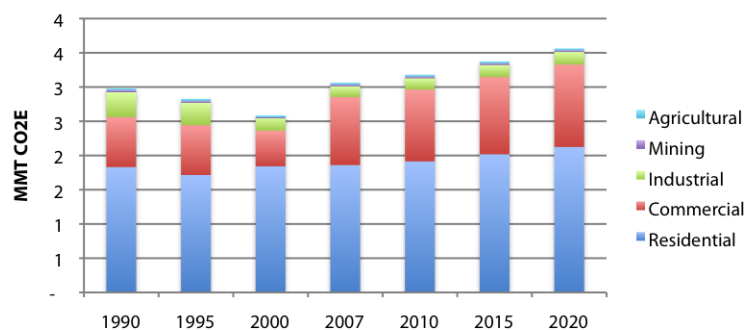


Figure 5. Natural Gas Consumption by Building Type in San Diego County (2006)

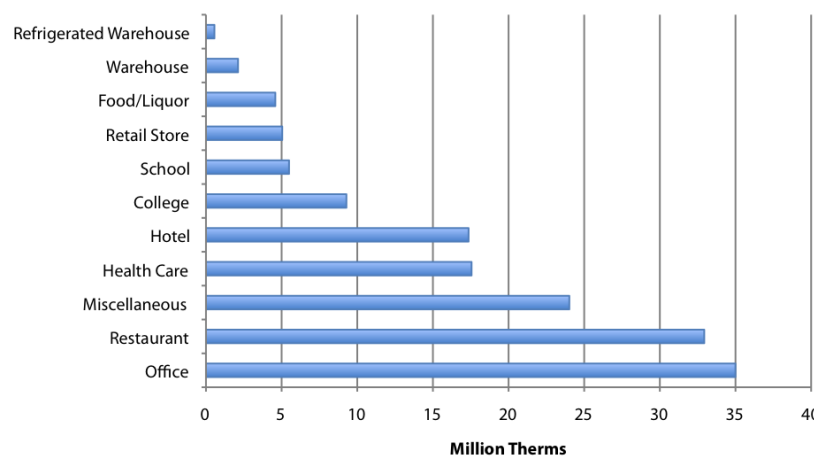
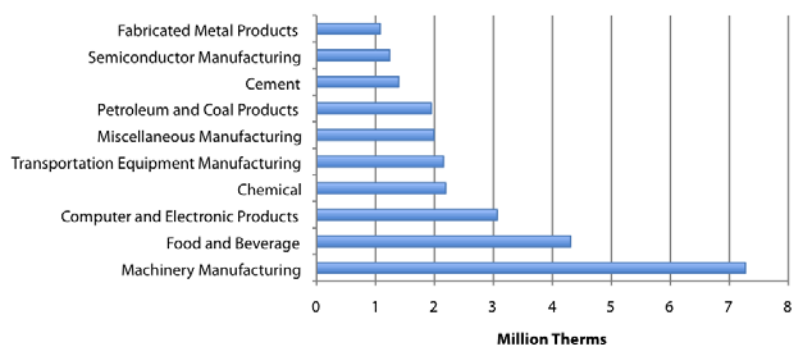


Figure 6. Natural Gas Consumption by Industrial Use in San Diego County (2006)

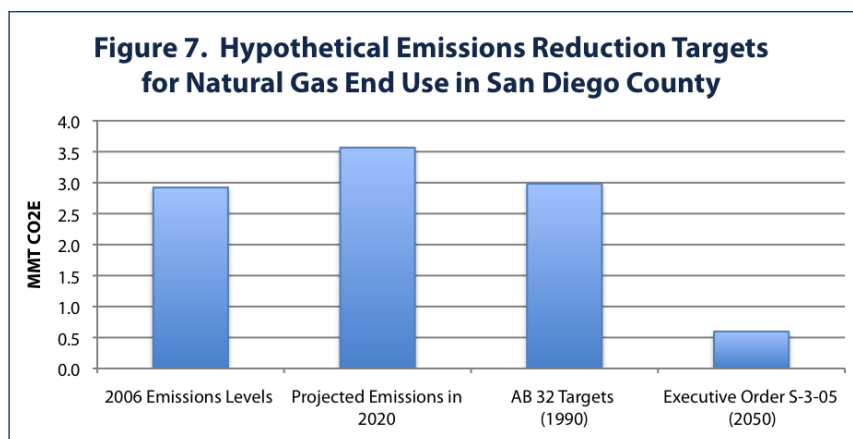


today are slightly lower than they were in 1990; however, projected growth in natural gas consumption will raise greenhouse emissions rates above 1990 levels. To reach the AB 32 targets, emissions from natural gas end use will have to be decreased by 0.6 MMT CO₂E (16%) below the business-as-usual 2020 projected level of emissions.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05,

which establishes long-term targets

for GHG emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target toward which California regulations are aiming. Emissions will have to be reduced by 3 MMT CO₂E (83%) below projected 2020 levels. Figure 7 depicts the theoretical emissions reduction targets for natural gas end-use consumption.



2.2. Emissions Reduction Strategies for Natural Gas End Uses (Wedges)

California has been a leader in energy efficiency since the 1970s. California's building and appliance standards are among the most aggressive in the nation, and historically the state has had effective energy efficiency programs funded by a public benefits charge paid by all utility customers. Per-capita energy consumption in California has remained relatively flat over the past three decades owing in large part to these standards and programs. Reducing overall consumption and demand for electricity is a key component in the state's overall energy infrastructure planning, policy contained in the Energy Action Plan's loading order, which emphasizes energy efficiency as preferential resource.⁷ Similarly, efficiency is also a preferential method to reduce greenhouse gases.

Unlike other sectors, the only driver of emissions for the natural gas end-use sector is total consumption; therefore, the only method to reduce emissions is to reduce overall consumption. To meet the theoretical AB 32 targets by 2020 for this category, a 0.6 MMT CO₂E (16%) reduction in total end use consumption is needed. Determining the amount of natural gas consumption that can be reduced by 2020 is complex, and no single policy exists to achieve such a goal; rather, a combination of existing rules and regulations are evolving to contribute to significant reductions statewide. It is also possible that future legislation will initiate regulatory changes to accelerate efficiency. The project team considered these factors when determining the possibilities for reasonable natural gas reductions by 2020.

Energy efficiency programs funded by the customers of electric and natural gas utilities are a significant factor. The California Public Utilities Commission (CPUC) has regulatory jurisdiction over investor-owned utility expenditures for energy efficiency.⁸ An ongoing proceeding is considering the potential for long-term savings from these so-called public goods charge energy efficiency programs. Itron, Inc., has conducted a detailed analysis of this potential for this proceeding.⁹ Initial results for the SDG&E service area suggest a potential for natural gas reductions ranging from a base case of approximately 3% to a midrange case of 8% of projected total energy supply by 2020.¹⁰ Itron's base-case estimate assumes that future incentive levels are exactly what they were in 2006. Their midrange estimate assumes that incentives are set halfway between 2006 levels and the full incremental cost of an efficiency measure. Itron also included a high-range estimate, which assumes that the incentive level will be equal to the full incremental cost. Because this level of incentive is not likely to occur, the high-range scenario was not considered here.

The natural gas reduction estimates in the Itron study include savings from energy efficiency programs and from naturally occurring savings, those that would have occurred even without incentives, rebates, and other program activities. The estimate does not include savings from large industrial customers, of which the San Diego region has few, or new appliance and building standards, both of which would have a significant impact on energy use. Table 1 shows Itron's estimated natural gas savings potential for the SDG&E service territory.¹¹ The table includes the percentage of natural gas end use consumption the potential savings represent. For the purposes of this study, 2020 is the most relevant year, since that is the year AB 32 emissions reduction targets must be met.

Table 1. Natural Gas End Use Efficiency Potential (Million Therms)

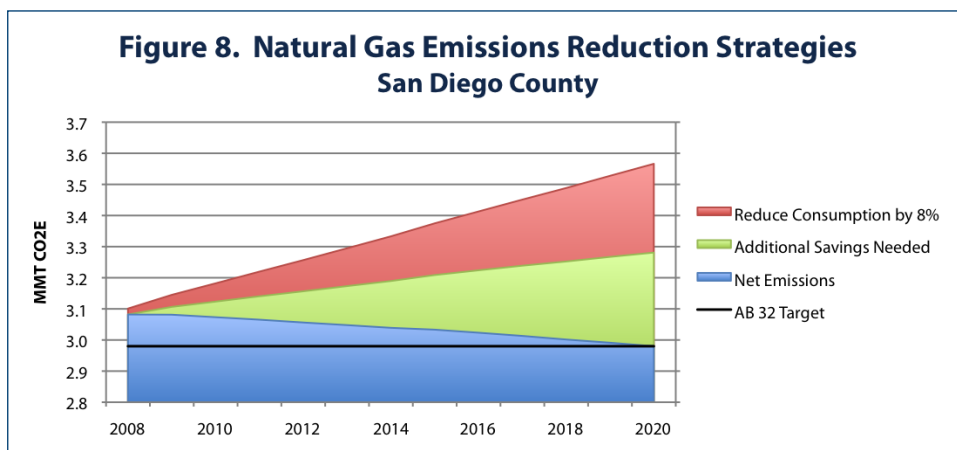
Year	Base Estimate	Base Estimate As % of Total Consumption	Mid-Range Estimate	Mid-Range Estimate As % of Total Consumption
2007	2.0	0.4%	3.0	0.5%
2008	3.0	0.5%	7.0	1.2%
2009	5.0	0.9%	11.0	1.9%
2010	6.0	1.0%	15.0	2.6%
2011	8.0	1.3%	19.0	3.2%
2012	10.0	1.7%	23.0	3.8%
2013	12.0	2.0%	27.0	4.4%
2014	14.0	2.3%	32.0	5.2%
2015	16.0	2.6%	36.0	5.8%
2016	17.0	2.7%	40.0	6.3%
2017	18.4	2.9%	43.2	6.8%
2018	19.8	3.1%	46.4	7.2%
2019	21.2	3.3%	49.6	7.6%
2020	22.6	3.4%	52.8	8.0%

Note: Values for 2018-2020 were interpolated based on Itron study results.

Using the Itron analysis as a base, the project team calculated the GHG emissions associated with a 8% (49 million therms) reduction in natural gas use in the region by 2020, which would result in a 0.3 MMT CO₂E reduction, roughly half of that needed to meet AB 32 targets. Given the uncertainties about how this reduction might be achieved, the project team chose to develop a general reduction wedge. Energy reductions associated with this wedge likely will be achieved through a combination of efficiency programs, appliance and new building standards, and other possible policy and statutory changes, including requirements for zero-energy buildings and efficiency upgrades when an existing building changes ownership.

In Decision 07-10-032, the CPUC established a policy goal for all new residential construction to be zero net energy by 2020 and for all commercial construction to be zero net energy by 2030.¹² Two pending bills in the California legislature seek to establish these zero-energy standards.¹³ Also, AB 1470 codified an incentive program for solar water heating, which will also contribute to this goal. Finally, in their Draft Scoping Plan, the California Air Resources Board (CARB) recommended a 5.6% reduction in statewide natural gas usage via energy efficiency. This is less aggressive than the 8% overall reduction projected here.¹⁴

Figure 8 shows the effect of an 8% reduction in natural gas consumption and the quantity of additional savings needed to reduce emissions to 1990 levels by 2020. If the region could achieve a reduction of 8%, it would then need to reduce emissions by an additional 0.3 MMT CO₂E to meet the hypothetical AB 32 emissions reduction targets by 2020.



3. Natural Gas End Use Methodology

The method for calculating greenhouse gas emissions from natural gas end use is relatively straightforward. Greenhouse gas emissions correlate directly to consumption, so the team estimated emissions on the basis of historical and projected consumption data provided by the California Energy Commission (CEC).¹⁵ In addition to the aggregated data in the staff forecast, the CEC provided detailed consumption data that allowed the project team to analyze consumption trends for each sector and subsector of the economy.

3.1. Natural Gas GHG Emissions Calculation

The project team calculated total GHG emissions (measured in carbon dioxide equivalent, CO₂E) by aggregating emissions of CH₄, CO₂, and N₂O, according to the following formula:

Greenhouse gas emissions (grams of CO₂E) = (standard cubic feet of natural gas) x (heat content in BTU/scf) x (fuel emissions factor g/BTU) x (global warming potential [GWP] factor)

Each part of the equation is described in more detail below.

Heat Content

The heat content of natural gas is a significant factor in determining emissions. On the basis of actual fuel use data from both the Federal Energy Regulatory Commission (FERC) Form 1 and the Energy Information Administration (EIA), the project team calculated weighted averages of the heat content of the natural gas consumed in the region for electrical generation during the period 1990-2006 (Table 2). By comparison, the heat content used by CARB for 1990, 1995, and 2000 was 1,027 BTU/scf. In 2004, the last year of the statewide inventory, CARB used 1,002 btu/scf.

Table 2 Weighted Average Heat Content for Selected Years (BTU/scf)

Table 2. Weighted Average of Heat Content for Selected Years

	1990	1995	2000	2005	2006
Heat Content (BTU/scf)	1,032	1,019	1,017	1,020	1,020

Fuel Emissions Factors

The project team used the fuel emissions factors for natural gas combustion provided by CARB.

- CH₄ - 1.00E-06 g/BTU
- CO₂ - 0.053 g/BTU
- N₂O - 1.00E-07 g/BTU

Global Warming Potential Factors

To calculate emissions from all greenhouse gases, it is necessary to convert emissions from CH₄ and N₂O into a form equal to the carbon dioxide equivalent. A global warming potential (GWP) factor is used to translate the GWP of a specific gas into the GWP of carbon dioxide. Each gas has its own factor. To calculate the carbon-dioxide-equivalent emissions from natural gas end-use consumption, we used a GWP factor for CH₄ of 21 and N₂O of 310.

3.2. Natural Gas Emissions Projections

Projections in this study are based on the CEC's Energy Demand Forecast for 2008-2018. These data were extended to 2020 via a linear extrapolation. The CEC forecast incorporates the effects of the 2005 building standards and currently funded energy efficiency programs through 2008.¹⁶

The project team recognized that complex interactions exist among and between categories when considering GHG reduction strategies. For example, increased use of natural gas as a transportation fuel may increase natural gas consumption yet result in an overall greenhouse gas reduction, as natural gas is a cleaner fuel than traditional transportation fuels. To the extent that these interactions are captured in the CEC demand forecast, they are captured here. Modeling the potential interactions among emissions categories is an area for further analysis.

End Notes

1. Emissions from natural gas used to produce electricity are included in the electricity category.
2. These categories are based on the natural gas consumption data provided by the California Energy Commission and may differ from those used by the California Air Resources Board.
3. California Energy Commission (CEC). California Statewide Residential Appliance Saturation Study: Volume 2, Study Results. Final Report. June 2004. Available at the CEC website http://www.energy.ca.gov/reports/400-04-009/2004-08-17_400-04-009VOL2B.PDF
4. Business-as-usual emissions projections are based on the California Energy Commission's Energy Demand Forecast for 2008-2018. See California Energy Demand 2008-2018 Staff Revised Forecast. November 2007. Available at <http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF> (Last viewed June 17, 2008).
5. The project team recognized that there could be complex interactions among and between categories – such as increased natural gas use to offset traditional transportation fuels, but it did not conduct an analysis to determine the effects of these interactions. To the extent that these are captured by the California Energy Commission, they will be captured in the projections presented here.
6. There appears to be a data inconsistency with year 2000 data from the CEC. The data for commercial consumption are significantly lower than for the preceding and subsequent years.
7. California Energy Commission, Energy Action Plan: 2008 Update, February 2008. Available at <http://www.energy.ca.gov/2008publications/CEC-100-2008-001/CEC-100-2008-001.PDF>
8. These include SDG&E, the Gas Company, Southern California Edison, and Pacific Gas & Electric. Other municipal utilities, such as Los Angeles Department of Water and Power, also have similar energy programs but are not regulated by the CPUC.
9. Itron, Inc., California Energy Efficiency Potential Study (draft final). Page 4-45 May 12, 2007. Available at http://www.calmac.org/publications/PG&E_EE_FcstModelReport_DraftFinal.pdf (last viewed June 3, 2008). See also <http://www.calmac.org/NewPubs.asp>.
10. Projected energy supply is based on the CEC forecast, which incorporates the effects of the 2005 building standards and currently funded energy efficiency programs through 2008. See California Energy Demand 2008-2018 Staff Revised Forecast. November 2007. Available at <http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF> (last viewed June 17, 2008).
11. Itron Study, op. cit., p. 4-84
12. See Decision 07-10-032 in Rulemaking R.06-04-010 at http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/74107.pdf.
13. AB 2030 seeks to develop standards for nonresidential buildings. AB 2112 seeks to develop standard for residential buildings.
14. CARB, Climate Change Draft Scoping Plan: A Framework for Change. June 2008.
15. California Energy Demand 2008-2018 Staff Revised Forecast. California Energy Commission (CEC), November 2007. Available at <http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF> (last viewed June 17, 2008).
16. For details on the CEC demand forecast see California Energy Demand 2008-2018 Staff Revised Forecast. November 2007. Available at <http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF> (last viewed June 17, 2008).



San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

Electricity Report

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September 2008





Electricity Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

Production and use of electricity is a significant source of greenhouse gas emissions (GHG). In San Diego County, the combination of emissions from power plants located in the region and electricity imported from outside the region accounts for about one quarter of regional GHG emissions. This report, a component of the San Diego County Greenhouse Gas Inventory project, provides an estimate of historical GHG emissions associated with electricity from 1990 to 2006 and future emissions to 2020 for San Diego County. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for the region's electricity category. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to reduce emissions to 1990 levels by 2020 – the statewide statutory target under AB 32. Finally, the report identifies and quantifies potential emissions reduction strategies to determine the feasibility of reducing electricity-related emissions to 1990 levels by 2020.

To the extent possible, the project team followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide GHG inventory. In some instances, when doing so could yield a more accurate or precise result, the project modified the CARB method.

This report, which is intended as an overview of the findings from research and analysis conducted for the electricity category, includes the following sections.

- Section 2 provides an overview of GHG emissions for electricity production and use in San Diego County, including total emissions, a breakdown of emissions by subcategory (residential, commercial, etc.), a summary of the highest emitting commercial building types and activities, projections to 2020, and reduction targets.
- Section 3 discusses the strategies necessary to reduce electricity-related emissions to 1990 levels by 2020.
- Section 4 provides a detailed discussion of the method used to estimate emissions for this category.

1.1. Key Findings

The key findings of the report are summarized below.

- In 2006, GHG emissions from the electricity sector totaled 9 million metric tons of carbon dioxide equivalent (MMT CO₂E), about 25% of San Diego County's overall emissions.
- Emissions from electricity use grew by about 2 MMT CO₂E (31%) between 1990 and 2006, exceeding population growth.
- Electricity use in the commercial sector accounted for 4 MMT CO₂E (44%) in 2006. The residential sector accounted for 3.1 MMT CO₂E (36%). Combined, these sectors represent 80% of total emissions from electricity use. The remaining emissions derive from agricultural, industrial, and other uses.
- Under the 2020 business-as-usual projection, emissions are expected to increase by 2 MMT CO₂E (28%).¹

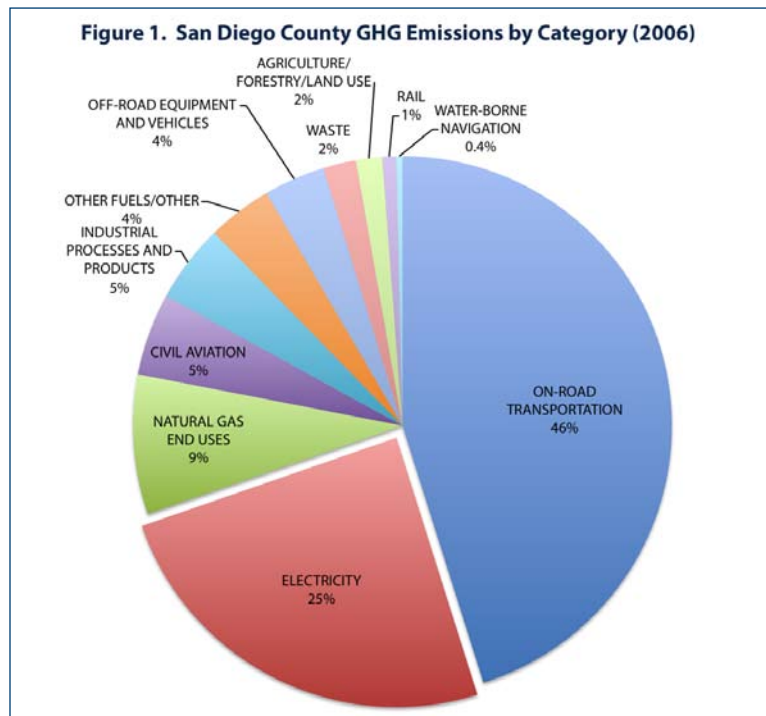
- The electricity sector would have to reduce its GHG contribution by just over 4 MMT CO₂E (40%) below the 2020 business-as-usual projection to meet AB 32 emissions reduction targets (1990 levels).
- To achieve the targets established in Executive Order S-3-05, reducing emissions 80% below 1990 levels by 2050, emissions from electricity would need to be about 1 MMT CO₂E (10 MMT CO₂E [88%] below the 2020 business-as-usual projection).
- Reducing emissions to 1990 levels by 2020 would require a combination of increasing renewable energy sources, enhancing energy efficiency, increased use of cogeneration, and purchasing cleaner fossil-fuel derived electricity.
- Achieving the existing Renewable Portfolio Standard of 20% renewable supply by 2010 and 33% by 2020 would reduce GHG emissions by 3 MMT CO₂E, accounting for 56% of the potential emissions reduction from the electricity sector.²
- Over the period from 1990 to 2006, approximately one-third of San Diego County's total energy supply was purchased from sources for which fuel use and location were unknown; therefore, any estimate of emissions from the electricity sector has some degree of uncertainty.

2. Greenhouse Gas Emissions From Electricity Production and Use

Electricity generation is a significant contributor to GHG emissions. As it does statewide, electricity accounts for about 25% of total emissions in the San Diego region (9 MMT CO₂E). Figure 1 shows the relative contribution of this category to San Diego County's total GHG emissions.

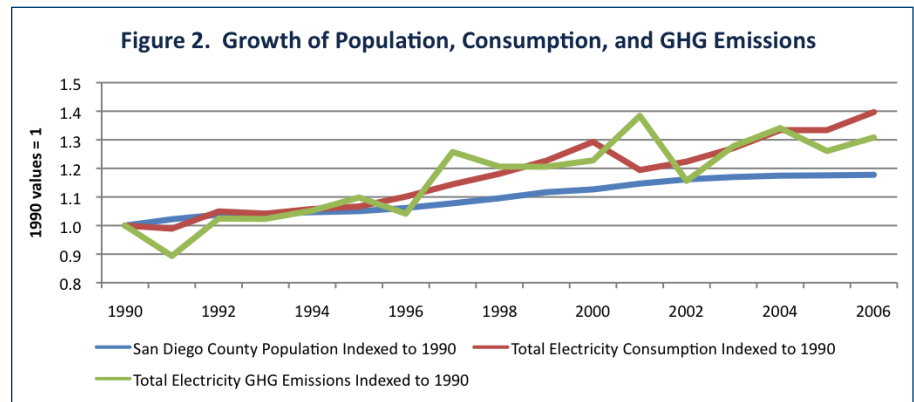
Electricity category totals include emissions from all electricity generated and consumed within the region and imported from outside the region but consumed in the region. Emissions from the following sources are included:

- **SDG&E-Owned Generation Assets.** Historically this included all of the large power plants in the region and several gas turbines. After electricity restructuring, these plants changed ownership but still operate in the region.
- **SDG&E Purchased Power.** This is all the electricity purchased by SDG&E to supplement their own generation, including energy from power plants located in the region and outside the region.
- **California Department of Water Resources (DWR) Contracts.** During the electricity crisis of 2000-2001, the DWR entered into contracts on behalf of the utilities in California. Several of these contracts were allocated to SDG&E.

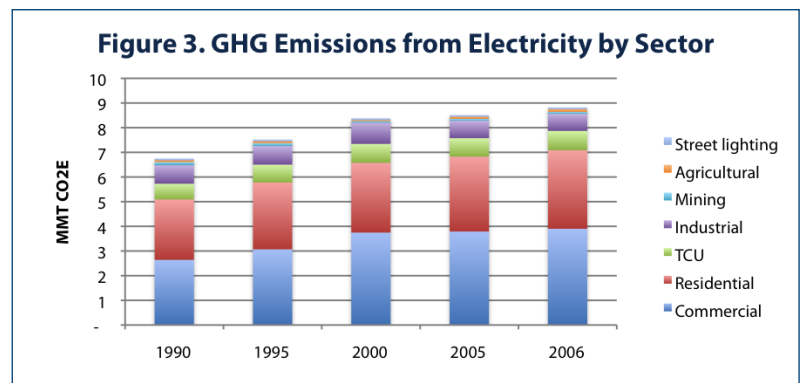


- **Direct Access.** Electricity is supplied by entities other than SDG&E under existing direct-access contracts. (Emissions from this sector would not be included in an estimate of greenhouse gases for SDG&E only.)
- **Self-Serve Generation.** Emissions from electricity generated by individual customers for their own use is also included in the inventory. For example, if a customer has a distributed generation system and consumes all the energy from the system, this electricity is not included in the purchased power data, as no energy was sold to SDG&E.

Because all electricity consumed in the San Diego region is included in this emissions estimate, it will by definition vary from other estimates that cover SDG&E only, as given in the mandatory reporting process required by the California Air Resources Board or reported publicly through the California Climate Action Registry.

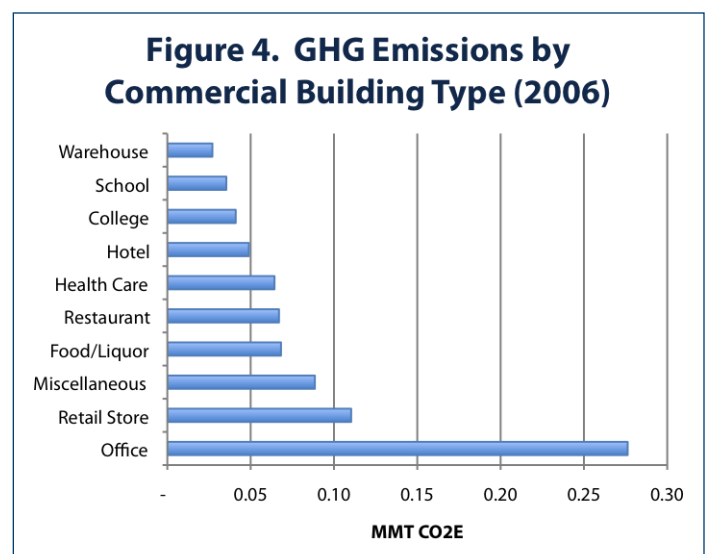


Emissions from electricity generation increased by 2 million metric tons of CO₂ equivalent (MMT CO₂E) or about 31% during the period 1990-2006. Historically, GHG emissions trends have mirrored those of electricity consumption and population growth. As shown in Figure 2, which indexes emissions, electricity use, and population growth to 1990 levels, in recent years GHG emissions from the electricity sector are growing faster than population growth.



As the economy's greatest consumer of electricity, the commercial sector produces most of the associated GHG emissions. This sector is responsible for 4 MMT CO₂E (44%) of emissions, while the residential sector accounts for approximately 3 MMT CO₂E (36%). Transportation, communications, and utilities (TCU) accounts for 0.8 MMT CO₂E (9%), and San Diego County's relatively small industrial sector accounts for 0.7 MMT CO₂E (8%). Figure 3 shows the relative emissions of each sector for selected years from 1990 to 2006.

Emissions within the commercial sector may be split between commercial buildings and other commercial activities.³ Figure 4 shows the top 10



emitting commercial building types. Office buildings emit more than any other buildings type by a large margin.

Figure 5 shows the top 10 emitting categories in the “commercial other” sector. National security activities, including military bases, emit nearly three times the amount of the next closest category, though they have significantly lower emissions than office buildings.

The emissions rate of the San Diego region’s electricity sector, expressed in pounds per megawatt-hour, has remained relatively flat from 1990 through 2006 (Figure 5). The current emissions rate of 968 pounds per megawatt hour (lbs/MWh) is about 3% below 1990 levels. From 1990 through 1995, SDG&E purchased significant amounts of virtually emissions-free geothermal energy from the Mexican Commission Federal de Electricidad (CFE). Also, SDG&E’s portion of the San Onofre Nuclear Generating Station (SONGS) represented a greater percentage of overall energy use in the early part of the time period evaluated.

Today, SDG&E’s supply mix is mostly natural gas and nuclear with a growing portion of renewables. As SDG&E complies with the Renewable Portfolio Standard (RPS) requirement of 20% renewable sources by 2010, it is likely that the overall emissions rate will decline further. Figure 6 also shows the

projected emissions rates as the 2010 target is met and if the RPS requirement is expanded to 33%.⁴

As mentioned above, it is important to note that the emissions rates presented here are for total energy supply for the San Diego region, including direct-access sales, which accounted for approximately 17% of total energy supply in 2006, and on-site electrical generation not sold to the utility.

2.1. Emissions Projections and Reduction Targets

Given a business-as-usual trajectory, emissions from the electricity sector will be approximately 11 MMT CO₂E in 2020, a 28% increase over 2006 levels and a 67% increase over 1990 levels. Figure 7 shows the emissions levels under the business-as-usual scenario, which projects emissions at the 2006 rate of emissions (lbs/MWh) and assumes no other changes.^{5, 6}

Figure 5. GHG Emissions from Other Commercial Activities (2006)

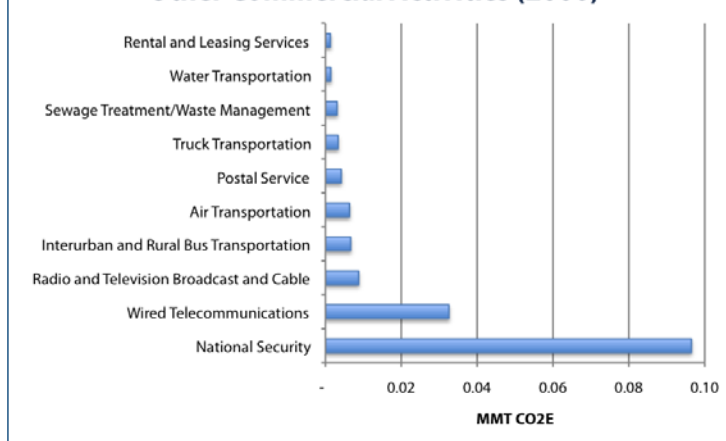


Figure 6. GHG Emissions Rate for Total Electricity Used in San Diego County

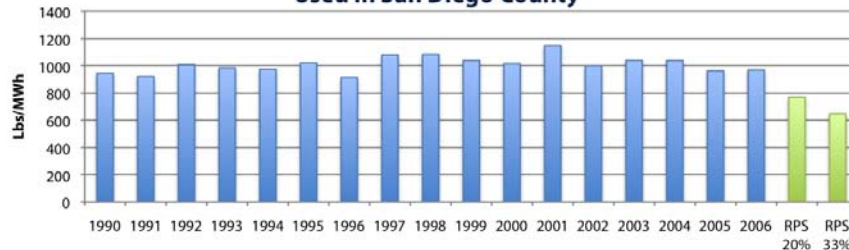
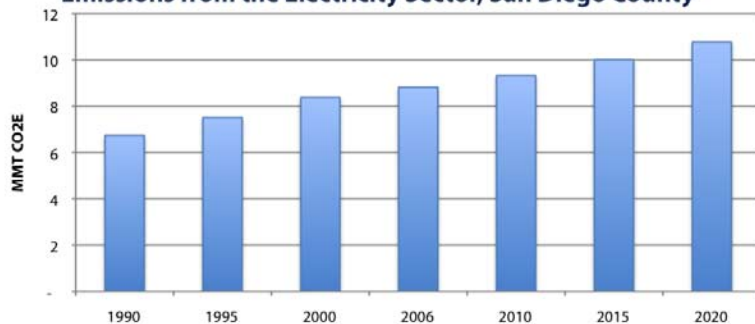
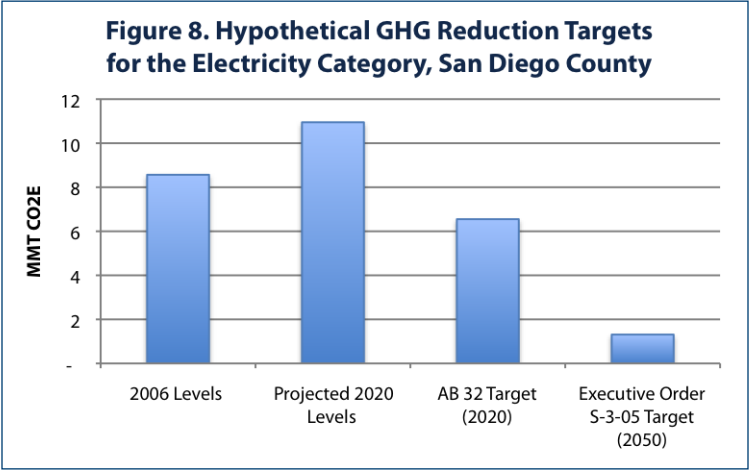


Figure 7. Business-as-Usual Projection for GHG Emissions from the Electricity Sector, San Diego County



In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on GHG emissions in California. AB 32 seeks to reduce statewide GHG emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County. To meet the targets established by AB 32 (1990 levels by 2020) the San Diego region would have to reduce its 2020 emissions from electricity use by 4 MMT CO₂E – a 40% reduction.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for GHG emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, total emissions from electricity would have to be reduced to just over 1 MMT CO₂E – a reduction of 10 MMT CO₂E (88%) below the 2020 business-as-usual projection. Figure 8 shows projected 2020 and actual 2006 emissions levels compared to the AB 32 and Executive Order S-3-05 targets.



3. Emissions Reductions Strategies (Wedges)

To reach emissions reductions targets set by AB 32, the electricity sector will have to reduce emissions by approximately 4 MMT CO₂E below the business as usual projection for 2020. Emissions in the electricity sector are driven primarily by total consumption and fuel type. One clear strategy is to reduce the total energy consumed in the region. Another significant strategy is to generate electricity from renewable sources that have nominal or no emissions.⁷

To illustrate how the region could achieve the AB 32 targets and reduce emissions by 4 MMT CO₂E, the project team developed several strategies and calculated the potential emissions reductions for each. The results were used to develop reduction “wedges,” illustrated in Figure 9. This approach was adapted from the well-known study by Pacala and Socolow, demonstrating that global emissions could be reduced to levels that would stabilize climate change with existing technologies.⁸ They

Table 1. Electricity Category Emissions Reduction Strategies (Wedges)

Emission Reduction Wedge	Emissions Reduction MMT CO ₂ E	Percentage of Total Reduction	Percentage of AB 32 Goal for Electricity
Renewable Portfolio Standard 20%	2.0	37%	45%
Renewable Portfolio Standard 33% (Incremental)	1.1	20%	24%
Reduce Electricity Consumption 10%	1.0	19%	23%
Cleaner Electricity Purchases (≤1100 lbs/MWh)	0.6	12%	15%
Replace Boardman Contract	0.3	5%	6%
Increase CHP by 200 MW	0.2	4%	5%
400 MW of Distributed Photovoltaics	0.2	4%	5%
Total	5.4	100%	122%

took the total reductions needed to stabilize emissions and split that amount into equal parts or wedges, each wedge representing a certain amount of emissions reduction. The project team followed a similar approach to show how the San Diego region might reduce its GHG emissions to meet AB 32 targets.

The team developed seven wedges to reduce GHG emissions from the electricity sector to 1990 levels. Each wedge is based in part on existing statutes, policy directives currently under consideration, or contractual terms (in the case of the Boardman power plant). Table 1 shows each wedge and the amount of emissions that it could reduce by 2020. The combined emissions reduction represented by these seven wedges is 5 MMT CO₂E, more than the total amount needed to reach the 1990 levels by 2020. The potential emissions reductions from the electricity sector represent approximately one third of the reductions needed from all sectors to meet the AB 32 target.

The order in which one calculates each wedge affects the magnitude of each wedge and the overall emissions reduction amount. This is because there are interactions between and among the wedges such that one wedge can affect the potential emissions reduction of another. In reality, all wedges would take place simultaneously, but to estimate the magnitude of each wedge, it was necessary to calculate the wedges discretely. For simplicity, the project team chose to calculate the wedges in an order based on the Energy Action Plan's loading order: energy efficiency, renewable energy, distributed generation, clean fossil-fuel generation.⁹

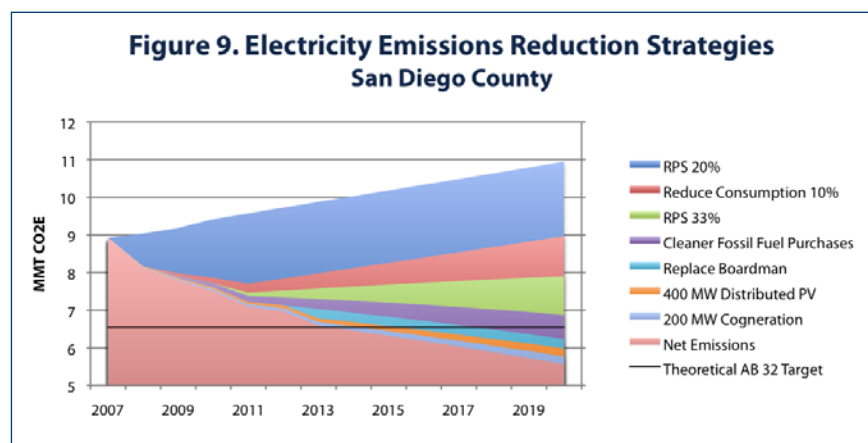


Figure 9 shows how each wedge reduces emissions from the business-as-usual projection.

3.1. Renewable Portfolio Standard – 20% by 2010

California's Renewable Portfolio Standard (RPS) requires the state's three investor-owned utilities to provide at least 20% of energy supplies from renewable sources by 2010.¹⁰ According to the California Public Utilities Commission, California's three major utilities supplied, on average, 13% of their 2006 retail electricity sales with renewable power.¹¹ SDG&E currently supplies about 6% of its sales with renewable energy.¹² To calculate the potential emissions reduction to meet the 20% RPS, we assumed the current level of 6% and that SDG&E attains its 20% goal by 2010 – a 14% percentage point increase. Achieving the 20% standard would yield 2 MMT CO₂E in GHG emissions reductions, representing about 37% of all the emissions reductions from the electricity sector.¹³

3.2. Renewable Portfolio Standard – 33% by 2020

The California Energy Commission's Integrated Energy Policy Report for 2007 recommends increasing the RPS to 33% by 2020.¹⁴ In recent years, legislation has been introduced to codify this policy, but none has yet been approved.¹⁵ For purposes of the wedge analysis, we calculated the impact of supplying 33% of all regional energy needs with renewables by 2020. The reductions associated with achieving a 33% standard would be 1 MMT CO₂E, or about 20% of the total reductions from the electricity sector. The combined effect of achieving the current 20% standard and incremental renewable additions from a 33% standard would represent 57% of all reductions needed from the electricity sector.

3.3. Reduce Electricity Use by 10% by 2020

California has been a leader in energy efficiency since the 1970s. California has some of the most aggressive building and appliance standards in the nation and historically has had effective electric energy efficiency programs funded by a public benefits charge paid by all customers. Per-capita energy consumption in California has remained relatively flat over the past three decades due in large part to these standards and programs. Reducing overall consumption and demand for electricity is a key component in the state's overall energy infrastructure planning policy. The Energy Action Plan's loading order emphasized energy efficiency and lowering demand as preferred "resources."¹⁶ Such reductions are also preferred to reduce greenhouse gases.

Determining the amount of electricity consumption that can be reduced by 2020 is complex, and no single policy exists to achieve such a goal; rather, a combination of existing rules and regulations is evolving to contribute to significant reductions in the total electricity consumed statewide. It is also possible that future legislation will initiate regulatory changes to accelerate electricity savings. The project team considered these factors when determining reasonable amounts of electricity reduction.

Energy efficiency programs funded by the customers of electric and natural gas utilities are a significant factor. The California Public Utilities Commission (CPUC) has regulatory jurisdiction over investor-owned utility expenditures for energy efficiency.¹⁷ An ongoing proceeding is considering the potential for long-term savings from these "public goods charge" energy efficiency programs. Itron Inc. has conducted a detailed analysis of this potential for this proceeding.¹⁸ Initial results for the SDG&E service area suggest a potential for electricity reductions ranging from a base-case of approximately 6% to a midrange case of 8% of projected total energy supply by 2020.¹⁹ These amounts include savings from energy efficiency programs and from naturally occurring savings, those that would have occurred even without financial incentives and other program activities; but they do not include savings from large industrial customers, of which the San Diego region has few, or new appliance and building standards, both of which can have a significant impact on energy use. Using the Itron analysis as a base, the project team calculated the GHG emissions associated with a 10% reduction in total energy use in the region by 2020, which would result in a 1 MMT CO₂E reduction.

Given the uncertainty of steps to achieve emissions reductions from energy efficiency, the project team chose to develop a general energy reduction wedge rather than try to predict exactly how these savings would be realized. Energy reductions associated with this wedge likely will be achieved through a combination of efficiency programs, appliance and new building standards, and other possible policy and statutory changes, including requirements for zero-energy buildings and efficiency upgrades when existing buildings change ownership.

In Decision 07-10-032, the CPUC established a policy goal for all new residential construction to be zero net energy by 2020 and for all commercial construction to be zero net energy by 2030.²⁰ Two pending bills in the California legislature seek to codify this goal by establishing zero-energy standards for commercial buildings by 2020 and residential buildings by 2030.²¹ Further, AB 1109, approved in 2007, will develop efficient lighting standards, which are likely to result in significant energy savings over time.²² Finally, in their Draft Scoping Plan, the CARB recommended a 10% reduction in energy usage via energy efficiency.²³

3.4. Replace the Boardman Power Plant Contract with Clean Fossil Fuel Generation

Fuel type is the main factor in determining the level of GHG emissions from electricity generation. Coal is the most carbon-intensive fuel used to generate electricity for large-scale use. SDG&E does not own any coal-fired power plants; nevertheless, it is unclear precisely how much coal-derived electricity is included

in its total electricity portfolio. SDG&E has a contract with Portland General Electric in Oregon to purchase energy from the Boardman Power Plant, which uses coal to generate electricity. The contract is set to expire in 2013.²⁴ Replacing energy generated by the Boardman plant with energy from a state-of-the-art, combined-cycle natural gas power plant would yield significant net GHG emissions reductions.

In 2006, the Boardman plant emitted greenhouse gases at a rate of 2,197 pounds per megawatt-hour (lbs/MWh). By comparison, SDG&E's new Palomar plant had an emissions rate of 818 lbs/MWh (Figure 10). If the Boardman plant were replaced starting in 2014 with energy generated from a plant equivalent to the Palomar plant, assuming the 2006 level of energy purchased from Boardman is projected into the future, GHG emissions would be reduced by 0.3 MMT CO₂E annually.

3.5. Purchase Cleaner Fossil Fuel Electricity

In addition to the Boardman power plant, SDG&E has purchased fossil fuel-generated electricity from other electric utilities over the past decade, including PacifiCorp, Public Service of New Mexico, Tucson General Electric, Arizona Public Service, and Salt River Project. Each of these utilities has a different average emissions profile depending on the fuel mix used to generate electricity. Figure 11 shows the 2006 average emissions rates for all electricity generated by these utilities compared to the CARB default rate of 1,100 lbs/MWh, which is used to estimate GHG emissions from electricity when the fuel and geographical location of the power plant are unknown. Assuming that future electricity purchases are similar in quantity to those of 2006, if all electricity purchased from these entities had an emissions rate equal to the CARB default rate, 0.6 MMT CO₂E would be avoided. This estimate does not include the additional savings that could be realized if all unspecified power purchases, which represent significantly more electricity than that purchased from the utilities presented here, were for electricity with an average emissions rate of 1,100 lbs/MWh.

Figure 10. Emissions from Boardman and Palomar Plants (2006)

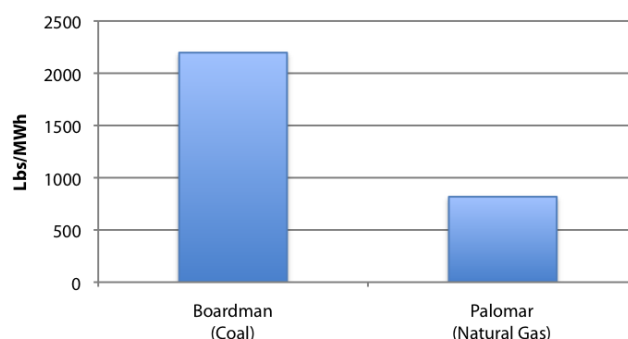
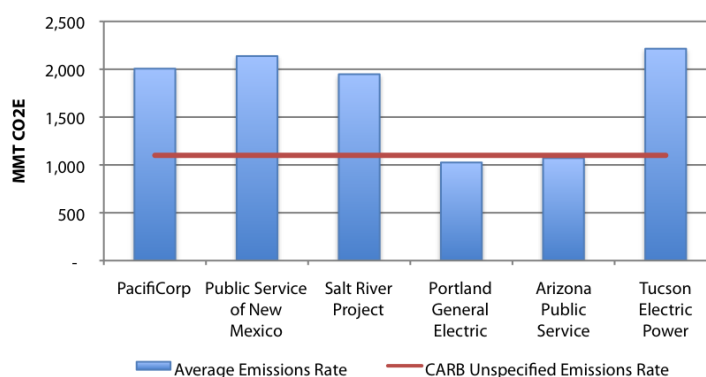


Figure 11. Average Emissions Rate for Sample of SDG&E Purchased Electricity Sources (2006)



3.6. Increase Cogeneration Capacity to 200 MW by 2020

Generating electricity is generally an inefficient process. Nationally in 2007, the average generation efficiency rate was 35%. This means nearly 65% of all of the primary energy used to generate electricity is wasted as exhaust heat.²⁵ One way to improve this process is to capture this heat and apply it to a useful purpose. Modern combined-cycle gas plants are more efficient than their single-cycle predecessors in part because they use waste heat. Cogeneration – also called combined heat and power (CHP) – is another way to improve the overall efficiency of electricity production. In this case, heat produced by the combustion process is captured to heat air or water or used in an absorption chiller to create cold water for air

conditioning. Increasing use of cogeneration in the region would reduce overall GHG emissions. A 2005 report by the Electric Power Research Institute and the California Energy Commission estimates that 155-420 MW of additional cogeneration potential exists in the SDG&E service territory, depending on adoption of policies and programs to promote cogeneration.²⁶ On the basis of these figures, under moderate market access and with the ability to export electricity into wholesale markets, the project team estimated that the SDG&E service territory could increase total cogeneration capacity by 200 MW, yielding a GHG emissions reduction of 0.2 MMT CO₂E by 2020.

To determine this emissions reduction, the project team calculated the difference between cogeneration and combined-cycle gas turbine, the likely other option for generating baseload electricity. Emissions from cogeneration were derived using an analysis by Energy and Environmental Economics, Inc. (E3), which showed that cogeneration installations would emit between 1024 and 1102 lbs/MWh during the period from 2009 through 2020.²⁷ Emissions from cogeneration are divided roughly equally between the production of electricity and thermal energy for other uses. For simplicity, the project team credited the electricity sector the amount of GHG savings associated with the thermal energy; that is, the amount of emissions avoided by using waste heat in lieu of natural gas for thermal needs. For natural gas combined-cycle emissions, the team used an emissions rate of 818 lbs/MWh, equal to that of SDG&E's Palomar plant in Escondido for 2006. Emissions savings would increase if compared to either the average emissions rate of the San Diego region or to peaking electricity resources.

3.7. Installation of 400 MW of Distributed Photovoltaics by 2020

In Decision D.06-12-033, the CPUC authorized expenditure of over \$2 billion to fund the California Solar Initiative.²⁸ The overall goal of the program is to install 1,750 MW of photovoltaics statewide by 2016. Funding is divided among the investor-owned utilities in California on the basis of energy consumption. The SDG&E service area will receive funding over the program period that is expected to support 180 MW of new photovoltaic systems by 2016. After the California Solar Initiative is implemented, since it is likely that the amount of capacity installed will increase annually as photovoltaic prices fall, the project team calculated a wedge showing the GHG reductions associated with 400 MW of photovoltaics, which represents a significant increase over what is expected from the California Solar Initiative. This is higher than the level of photovoltaics that CARB assumes will be installed by 2020 in their Draft Scoping Plan.²⁹

The emissions reduction resulting from 400 MW of photovoltaics is the smallest wedge, representing 0.2 MMT CO₂E. A portion of photovoltaic electric production occurs during peak, when the emissions rate is higher than the average emissions rate owing to use of lower efficiency resources. Emissions savings from installing this technology might be higher if this were taken into account.

3.8. Other Potential Wedges

The wedges above represent either existing law or policy directives or achievable savings using existing technologies. Other potential wedges exist that were not calculated as part of this analysis. Two areas in particular could offer further reductions. While nuclear energy raises many questions about storage of spent fuels, cost, and time to implement, it is generally an emissions-free method to generate electricity. The region already receives a significant amount of energy from the San Onofre Nuclear Generation Station (SONGS). Currently, California statute prohibits granting of new nuclear permits until a long-term storage solution is found.

Another possibility is carbon capture and storage from coal-fired generation. Carbon is injected into large underground or underwater cavities for long-term storage. With abundant coal supplies, such technology could help the United States meet future energy needs cleanly.

4. Electric Category Emissions Inventory Methodology

To determine GHG emissions from electricity generation in the San Diego region, the project team calculated the total amount of electricity needed in the region – including energy transmission and distribution losses and imported electricity – and used actual fuel data when available to calculate the associated GHG emissions. In some instances, no data were available to determine the fuel used to generate electricity. In those cases we used an estimated emissions rate (lbs/MWh) or developed a proxy based on similar fuel data. The following sections give more detail on each step of the process.

4.1. Energy Supply Data Sources

In general, the study relied on Federal Energy Regulatory Commission Form 1 to determine the region's overall energy supply and the eventual disposition of that supply, including data from the following sections of the form:

- **Purchased Power (Account 555):** SDG&E generates a portion of the electricity needed to supply regional needs using its own power plants. To supplement that, SDG&E purchases electricity from generation sources located in and out of the region. Account 555 includes, among other things, the entities from which SDG&E purchased energy and the amount purchased. These data were used to develop a detailed database of all SDG&E electricity suppliers. Between 1990 and 2006, SDG&E purchased electricity from more than 170 entities.
- **Electric Energy Account:** This account supplies data for total electricity sources and disposition for the year. Sources include the total generated, purchased, exchanged, and transmitted across the utility-owned transmission, as well as the losses incurred by others who wheel energy. Disposition includes sales to consumers, sales for resale, energy furnished without charge, energy used by the utility itself, and such other losses as those in transmission and distribution.
- **Steam-Electric Generating Plant Statistics (Large Plants):** This section of the FERC Form 1 supplies data on the total energy produced and fuel consumed by large power plants owned by SDG&E.

4.2. Determining Total Energy Supply

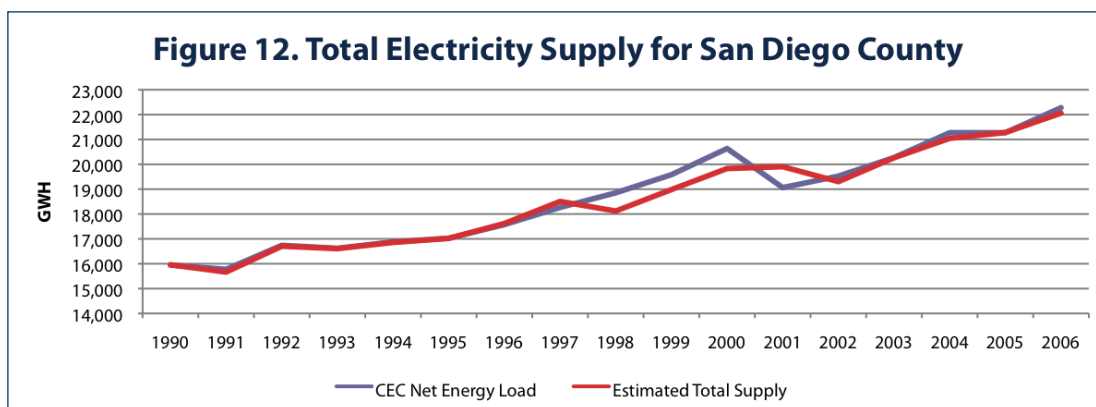
To determine the greenhouse gases associated with electricity generation, the team calculated total energy supplies for the region, the quantity of electricity needed by customers. It included electricity from SDG&E-owned generation assets, electricity purchased by SDG&E, electricity sold to customers who get electricity from a provider other than SDG&E (i.e., direct access), electricity associated with the California Department of Water Resources contracts issued during the 2000-2001 California electricity crisis, and on-site electricity generation used to offset customer load (self-serve). In addition to these sources, the calculation included transmission and distribution losses associated with all energy use.

The calculation was based on the following data sources, which were obtained from FERC Form 1 data unless otherwise noted:

- **SDG&E Net Generation:** the total amount of electricity generated by SDG&E-owned assets.
- **Total Power Purchased:** the total purchased by SDG&E to supplement its own generation.
- **Sales for Resale:** energy purchased and then resold, typically a negative number.

- Net Exchanges: contractual exchanges of electricity between two entities.
- Transmission Losses by Others: losses associated with electricity wheeled across the SDG&E's transmission system, counted as supply since they serve on-system demand.
- Direct-Access Sales (Sempra Energy SEC Filings): electricity supplied to customers from suppliers other than SDG&E. Direct-access totals include transmission and distribution losses of approximately 7.5%.³⁰
- Department of Water Resources Contracts: energy associated with DWR contracts assigned to the SDG&E territory. No public data were available, but energy totals were derived from EIA data. These also included transmission and distribution losses of 7.5%.³¹
- Self-Serve Energy (California Energy Commission): total energy generated on the customer's premises to serve on-site load was included in the energy supply total. Only nonphotovoltaic self-serve energy was included.

Since this project focused on San Diego County, the electricity associated with the small portion of Orange County that SDG&E serves, which was about 9% in 2006, was subtracted from the totals. Figure 12 compares the estimate of total energy supply developed by the project team with the latest forecast for net energy load from the California Energy Commission (CEC). The estimates matched up very well for all years except 1998-2001, which varied by up to 5% at times. This mismatch is likely attributable to data-reporting inconsistencies during the California electricity restructuring period and the energy crisis of 2000-2001. For the purposes of this study, the intermediate years are not as important as 1990 and 2006, both of which match up very well.



An estimate of the GHG emissions from each component part of the total supply was calculated. This helped to ensure that no double counting of energy values occurred. The method used to calculate emissions from each of these elements is discussed in detail below.

4.3. Emissions from SDG&E Net Generation

To calculate the total GHG emissions from SDG&E-owned generation assets, the project team used data from FERC Form 1 Electric Energy Account to determine the total amount of fuel combusted. For this and all other calculations to estimate GHG emissions from electricity production, fuel data, heat content, CARB emissions factors for CO₂, CH₄, and N₂O, and global warming potential (GWP) factors were used to calculate carbon dioxide equivalent. The basic equation for this calculation follows.

CO₂ Equivalent = [(Amount of fuel consumed) x (average heat content of fuel) x (CARB Emissions Factor – for CH₄, CO₂, and N₂O) x (GWP factor)]

Table 2 provides an example of this calculation for the Encina power plant in 1990.

Table 2. 1990 Encina Power Plant Emissions - Sample Calculation

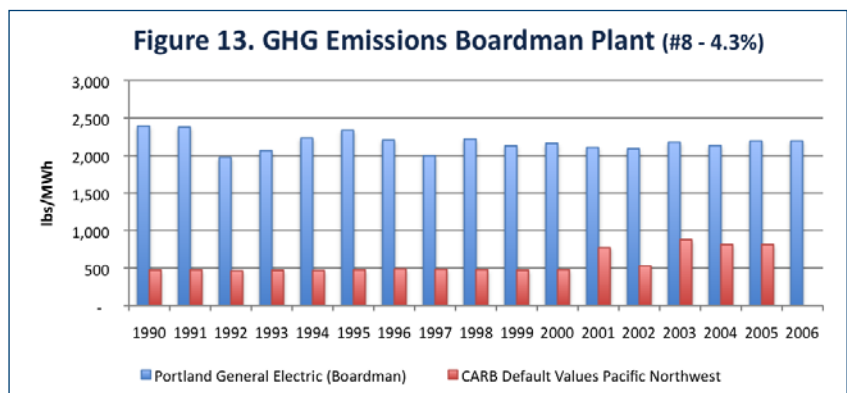
Fuel Type	Fuel Consumed	Average Heat Content (BTU/Unit)	Greenhouse Gas	CARB Emissions Factor (grams/BTU)	Global Warming Potential Factor	Total CO ₂ Equivalent (grams)	Total CO ₂ Equivalent (MMT)
Natural Gas (mcf)	15,524,550	1,035,000	CH ₄	0.000001	21	337,426,094	0.0003
Natural Gas (mcf)	15,524,550	1,035,000	CO ₂	0.053		851,599,190,250	0.85
Natural Gas (mcf)	15,524,550	1,035,000	N ₂ O	0.0000001	310	498,105,187	0.0005
Distillate Fuel Oil (bbl)	700,969	6,203,694	CH ₄	0.000003	21	273,961,622	0.0003
Distillate Fuel Oil (bbl)	700,969	6,203,694	CO ₂	0.073		317,882,453,820	0.32
Distillate Fuel Oil (bbl)	700,969	6,203,694	N ₂ O	0.0000006	310	808,839,075	0.0008
Total						1,171,399,976,049	1.2

4.4. Total Purchased Power

SDG&E purchases a significant portion of electricity each year to supplement the amount they generate; therefore, this is an important component of the inventory. We used FERC Form 1 Purchased Power (Account 555) data from 1990 through 2007 to identify all entities that sold energy to SDG&E. These data were used to create a database that enabled us to see how much each supplier sold to SDG&E each year and to identify which suppliers sold the most electricity to SDG&E over the period studied.

The project team categorized each supplier by fuel and region. For region, we indicated if the information was available, whether the energy producer was located in the Pacific Northwest (PNW); Pacific Southwest (PSW); San Diego County; California; or an unspecified location. For fuel source, we used the following categories: unspecified, natural gas, coal, nuclear, digester gas, landfill gas, biomass, wind, and hydro. To be consistent with the method used by CARB and to account for transmission and distribution losses, we added a 7.5% loss factor to purchases that we knew originated outside the region. Because this project focused on San Diego County, energy use associated with Orange County demand (approximately 9%) was omitted.

Estimates of emissions from purchased electricity were derived by multiplying the total energy purchased by an emissions factor (lbs/MWh). Three different methods were used to calculate emissions levels, depending on the level of information available about the supplier and power plant: calculations based on actual fuel data, calculations based on default CARB multiplier, or calculations based on an average emissions profile of the entity selling power to SDG&E.



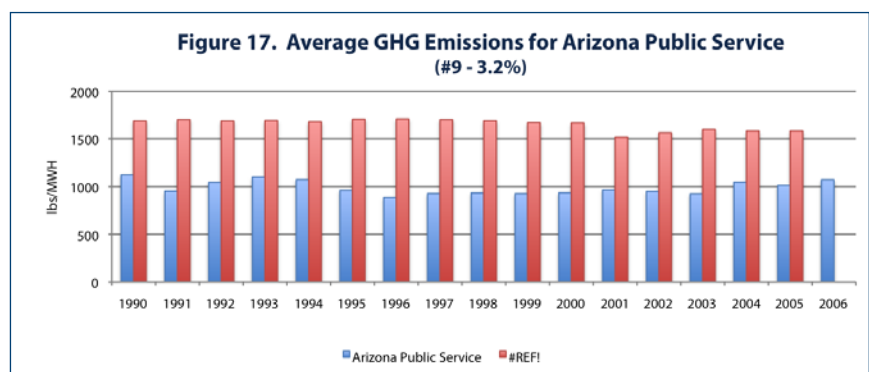
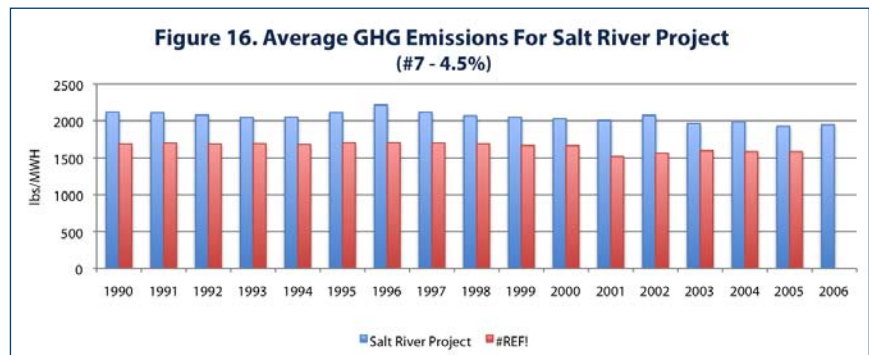
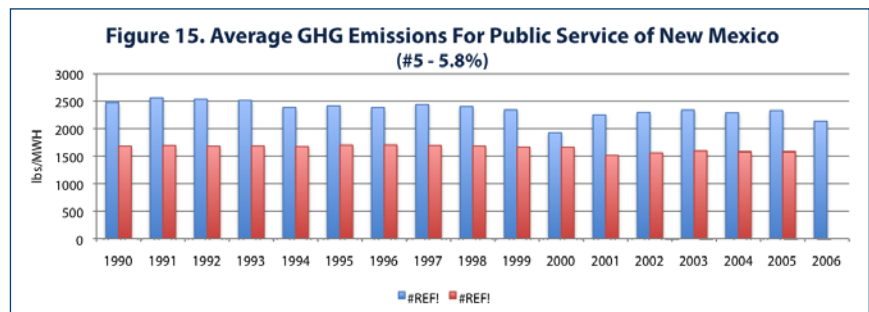
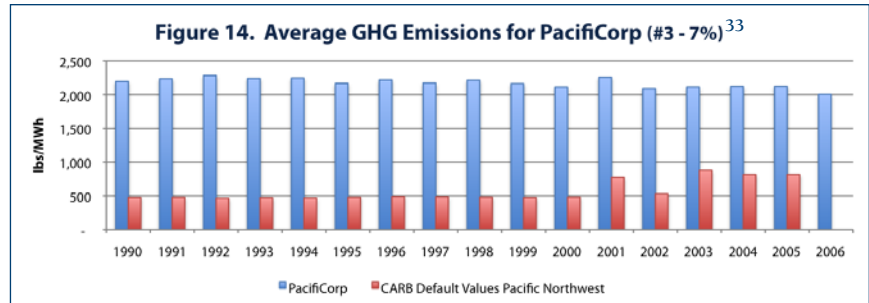
In the case of known locations and fuels, such as the Boardman coal-fired plant owned by Portland General Electric in Oregon, we knew the fuel and amount of energy sold, so we could use actual fuel and heat content data from EIA to calculate emissions levels for each year SDG&E purchased electricity from this power plant. Figure 13 shows the results of calculations to determine historical emissions rates from the Boardman plant and compares them to the default emissions factors developed by CARB for unspecified electricity purchased from the Pacific Northwest. Had we used the CARB default value for the energy associated with the Boardman plant instead of the actual emissions, the results would have underestimated the emissions. Portland General's Boardman plant was the eighth-largest supplier, producing 4.3% of the power purchased by SDG&E, during this period.

In cases where we did not have complete information about the location and fuel, we multiplied the energy values (MWh) by CARB emissions rates (lbs/MWh) for each category:

- Unspecified Geography/Unspecified Fuel: CARB value of 1,100 lbs/MWh.
- PNW, unspecified fuel: CARB default value for PNW for each year.
- PSW, unspecified fuel: CARB default value for PSW for each year.

In the third method, we calculated average emissions profiles for the utilities that sold the most electricity to SDG&E over the period 1990-2007. For six of the top known suppliers, we developed an average emissions rate (lbs/MWh) with actual fuel, heat content, and net energy generation numbers: PacifiCorp, Public Service Company of New Mexico, Salt River Project, Portland General Electric, Arizona Public Service, and Tucson Electric Power Company. Combined, these utilities supplied 26% of SDG&E's total purchased power between 1990 and 2007. Figures 14-18 show the average GHG emissions rate for each utility compared to the otherwise applicable CARB default rate. The figure title is followed by the rank of the supplier and the percent of purchased power supplied during this period.

The CEC has recommended a method to account for emissions from imports using a dispatch approach, assuming a utility supplier would use its inexpensive energy (coal and nuclear) to satisfy its own needs and sell higher cost energy (natural gas) to others.³² In the case of Pacificorp, whose actual emissions were significantly higher than the default CARB value, the energy generation portfolio was dominated by coal and there was little natural gas to sell. In the case of the suppliers



from the Pacific Southwest, the difference in emissions rates was not significant – in the case of Arizona Public Service the composite emissions rate was lower than the CARB default value – and their overall contribution to total energy supplies was relatively small.

4.5. Cogeneration

Taken together, all cogeneration purchases make up the largest energy supplier over the 17-year period. We knew the location of several cogeneration suppliers outside the region, such as Yuma Cogeneration Associates. We used actual fuel data for these to calculate GHG emissions levels. We made the simplifying assumption that all other cogeneration was located in the region.

While we had data on fuel use for some of the cogeneration plants located in the region, the FERC Form 1 data only provide an aggregated energy number. To determine GHG emissions, we multiplied this by a representative emissions rate (lbs/MWh) calculated using actual fuel and energy data for a sample of cogeneration systems.

For purposes of calculating total GHG emissions from electricity, only emissions associated with electrical production were assigned to the electricity category. To split out the thermal portion, we used the results of analysis of actual data by E3 that showed 63% of emissions attributable to electricity and 37% to thermal generation.³⁴ The emissions associated with the thermal portion of cogeneration are assigned to the “Other Fuels/Other” category in the charts included in the Executive Summary of the San Diego County Greenhouse Gas Inventory.

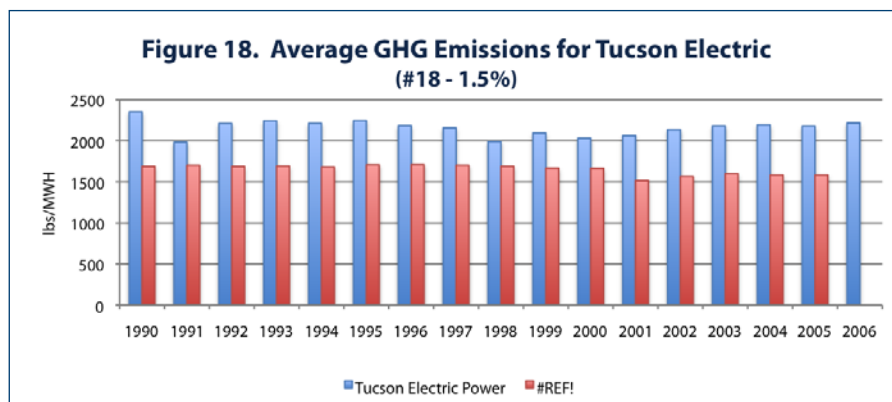
4.6. Other FERC Form 1 Categories

We included several other categories of FERC Form 1 data in our calculations, as follows:

- Sales for Resale: we calculated the emissions using average overall SDG&E emissions rate (lbs/MWh) for each year and then subtracted it from the total emissions for the region.
- Net Exchanges: we used average overall SDG&E emissions rate (lbs/MWh) for each year and then added/subtracted it from the total emissions for the region, depending on whether net exchanges were positive or negative.
- Transmission Losses by Others: we used average overall SDG&E emissions rate (lbs/MWh) for each year and then added it to the total emissions for the region. There were only “losses by others” in 1990 and 1992, and their emissions contribution to the total was minimal.

4.7. Direct-Access Sales

Data for direct-access sales were derived from Sempra Energy SEC Form 10-k, Table 5, for 1990-2006.³⁵ Consistent with CARB’s method, we added a 7.5% transmission and distribution loss factor to this energy.³⁶ Since no public data are available on the amounts and sources of specific transactions, we calculated emissions using the default CARB rate of 1,100 lbs/MWh.



4.8. Department of Water Resources Contracts

No historical data were available for the actual quantity of energy purchased as a result of ongoing Department of Water Resources contracts. We estimated energy levels by using FERC Form 1 Purchased Power data and EIA wholesale purchase data from Form 861.³⁷

For several years, the FERC Form 1 data on purchased power varied significantly from the EIA Form 861 data for wholesale purchases.

Table 3. Estimated Department of Water Resources Totals

Data Source	2001	2002	2003	2004	2005	2006
Wholesale Purchases EIA Form 861	13,568,541	10,935,412	12,075,204	13,109,328	12,856,203	12,424,852
Purchased Power FERC FORM 1	6,549,941	3,823,022	7,079,998	5,471,401	5,015,197	5,086,291
Difference	7,018,600	7,112,390	4,995,206	7,637,927	7,841,006	7,338,561

The difference was assumed to be the Department of Water Resources Contracts, as shown in Table 3.

Data were available for estimated energy from the DWR contracts in the future. SDG&E's long-term procurement plan includes an energy-balance estimate that forecasts energy associated with the DWR contracts.³⁸ We used these data to develop approximate energy supplies from each contract. We added transmission and distribution losses of 7.5% to those sources we knew originated outside the region.

For the largest contract, Sunrise, we estimated energy purchased and then used EIA fuel, heat content, and net energy generation data to develop an emissions rate (lbs/MWh). We multiplied that by the estimated energy supply from the plant. The second-largest contract was the Williams B contract; here, we used the CARB unspecified default value of 1,100 lbs/MWh.

4.9. Business as Usual Electricity and Greenhouse Gas Emissions Projections

As mentioned above, our total energy supply calculation matched the CEC calculation very well for most of the 1990-2006 period. To project into the future, we chose to use the CEC demand forecast data for 2008-2018. We used a linear projection of the CEC estimate for net energy load until 2020. To capture all the energy uses that create GHG emissions, we added total private supply (self serve). This became the basis for calculating the business-as-usual GHG emissions projections.

The CEC forecast incorporates the effects of the 2005 building standards and currently funded energy efficiency programs through 2008.³⁹ This is particularly relevant to the wedge that reduces electricity consumption by 10%.

4.10. Limitations of the Methods

In general, the methods used to estimate total GHG emissions for the electricity sector could be improved by access to more relevant data, particularly fuel and DWR Contract energy data. In many cases, fuel data were available, but in the cases of much of the electricity purchased by SDG&E to supply the region, the California Department of Water Resources contracts, and all of the energy associated with direct access, no data exist on the actual source of the electricity. Thus no data are available on the amount of fuel used. The total electricity supplied from these sources was approximately 30% of total energy supplies to the region: 11% from purchased power, 17% from direct access, and a fraction from unspecified DWR contracts. To overcome this data gap, CARB, the CEC, and the CPUC have developed default emissions factors for energy originating in the Pacific Northwest, Pacific Southwest, and from unknown origins. In at least one case shown here, use of the default factor resulted in significant underestimation of emissions.

Where possible, the project team used actual data, but in cases where data were not available, we used CARB default emissions rates (e.g., for unspecified electricity imports) or we developed a proxy rate based on actual data. For example, between 1990 and 2006 about 45% of the GHG emissions estimate associated with purchased power was derived using CARB default emissions values, 30% was derived using actual fuel consumption data, and about 15% was calculated using a proxy emissions rate developed with actual fuel consumption data. By definition, this introduces some uncertainty into the estimate.

As indicated above, we developed an estimate for the total annual energy associated with the DWR contracts. We used several data sets to develop the estimate, but to estimate emissions more accurately, actual fuel and energy generation data would be necessary.

End Notes

1. Business-as-usual emissions projections for the electricity sector exclude additions of renewable energy (to comply with the Renewable Portfolio Standard) above 2007 levels (6% of retail sales).
2. These totals are for renewable energy additions above 2007 levels (6% of retail sales).
3. This breakdown was included in the electricity data provided by the California Energy Commission.
4. This assumes that all renewable energy has no emissions.
5. Business-as-usual emissions projections are based on the California Energy Commission (CEC) Energy Demand Forecast for 2008-2018 (see California Energy Demand 2008-2018 Staff Revised Forecast. CEC November 2007, available at <http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF> [last viewed 6-17-08]) and exclude additions of renewable energy to comply with the Renewable Portfolio Standard above the levels achieved in 2007 (6%).
6. The project team recognized that there could be complex interactions between and among categories (such as increased electricity use to offset traditional transportation fuels) but did not determine the effects of these interactions. To the extent that these are captured in the CEC forecasts, they are captured here.
7. For purposes of this analysis, we assumed that renewable energy has no emissions.
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21. AB 2030 seeks to develop standards for nonresidential buildings. AB 2112 seeks to develop standard for residential buildings.
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San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and Strategies to Achieve AB 32 Targets

Other Transportation Report

Civil Aviation • Water-Borne Navigation • Off-Road Equipment & Vehicles • Rail

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September 2008





Other Transportation Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

On-road transportation (cars and trucks) is the largest category of greenhouse gas (GHG) emissions in the region; however, other transportation-related categories emit significant amounts of GHG emissions. This report presents GHG emissions totals for the other transportation categories included in the San Diego County Greenhouse Gas Emissions Inventory, consisting of off-road equipment and vehicles, civil aviation, water-borne vessels, and rail. Table 1 presents the subcategories that comprise each category included in this report. Together, these categories account for approximately 10% of San Diego County's GHG emissions in 2006.

Table 1. Other Transportation Categories and Subcategories

CIVIL AVIATION Interstate Flights Intrastate Flights	WATER-BORNE NAVIGATION Ocean Going Vessels (OGV) Harbor Craft
OFF-ROAD EQUIPMENT AND VEHICLES Construction and Mining Equipment Pleasure Craft Industrial Equipment Agriculture Equipment Other	RAIL TRANSPORTATION

This report provides historical emissions levels for each category from 1990 through 2006 and projected emissions through 2020. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for each component of this category. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to achieve the AB32 statutory target of 1990 levels by 2020. Finally, the report identifies and quantifies potential emissions reduction strategies in each component of this category to determine the feasibility of reducing emissions from other transportation sources to 1990 levels by 2020.

To the extent possible, the project team followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide GHG inventory. In some instances, when doing so could yield a more accurate or precise result, the project modified the CARB method.

This report is intended as an overview of the findings from research and analysis conducted for the categories noted above and includes the following sections.

- Section 2 provides an overview of GHG emissions, forecast and methodology for the civil aviation category.
- Section 3 provides the GHG emissions, forecast and methodology for the water-borne navigation category.
- Section 4 provides the GHG emissions, forecast and methodology for the off-road equipment and vehicles category.
- Section 5 provides a brief summary of the GHG emissions, forecast and methodology for rail transportation category.

1.1. Key Findings

The largest contributor to regional GHG emissions in this category is civil aviation, which accounts for about 5% of total emissions in the San Diego region. This is followed by the off-road category, which

contributes approximately 4% to the total regional GHG emissions. Figure 1 shows the relative contribution of each category to San Diego County's total GHG emissions.

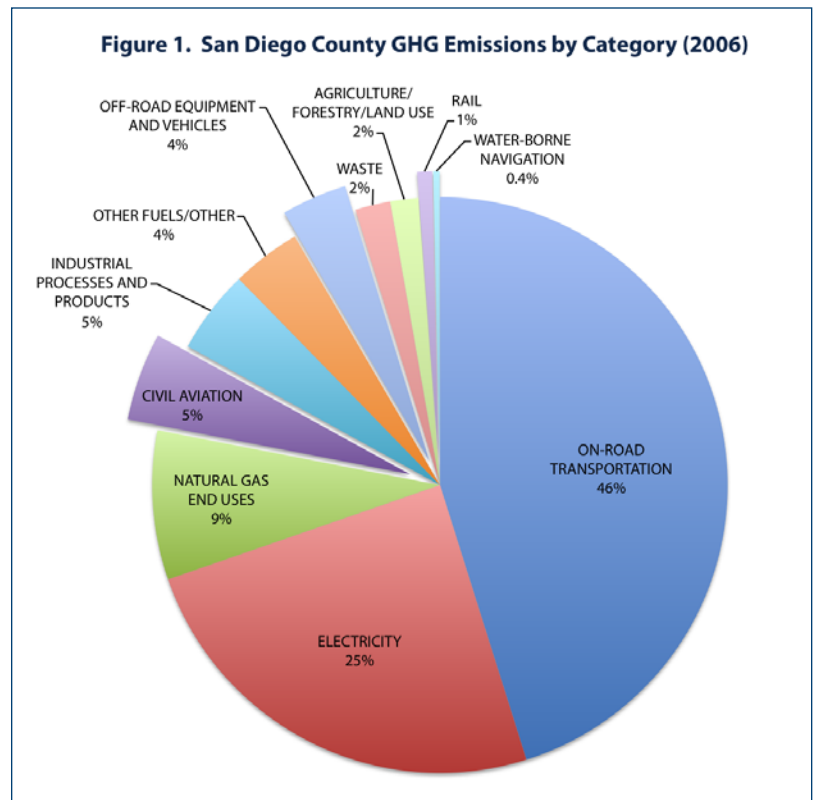
The key findings of each category included in this report are as follows:

Civil Aviation

- In 2006, emissions from the civil aviation category totaled 1.7 million metric tons of carbon dioxide equivalent (MMT CO₂E), an increase of about 42% over 1990 levels.
- Emissions from civil aviation account for approximately 5% of the total greenhouse gas emissions in San Diego County.
- The 1990 baseline for the civil aviation category is estimated as 1.2 MMT CO₂E. This includes emissions from domestic commercial flights – both intrastate (within CA) and interstate (from CA to another state), but not international flights.
- The emissions calculations are not directly comparable to the emissions provided by the California Air Resources Board statewide emissions inventory, which does not include emissions from state-to-state flights. These emissions constitute the major part of aviation emissions from San Diego.
- The 2020 business-as-usual (BAU) forecast is estimated to be 2.6 MMT CO₂E, a 53% increase over 2006 levels. If AB32 targets were applied to the civil aviation category, more than 54% reduction in emissions would be required to meet the AB32 target (1990 baseline) in 2020.

Water-Borne Navigation

- In 2006, emissions from the water-borne navigation totaled 127,000 MT CO₂E (metric tons), an increase of over 150% of 1990 levels. The 1990 baseline for the water-borne navigation category is estimated at 42,700 MT CO₂E. This includes emissions only from ocean going vessels (OGVs), interstate and international, and harbor craft, within the 24-mile territorial and contiguous zone.
- In 2006, emissions from water-borne navigation accounted for approximately 0.4% of the total greenhouse gas emissions in San Diego County.
- The 2020 business-as-usual (BAU) forecast is estimated to be 180,595 MT CO₂E, an increase of 42% above 2006 levels. The 2020 BAU forecast includes benefits to be obtained from the 2007 Shore Power Regulation and the 2005 Auxiliary Engine regulation affecting OGVs.³
- If AB32 targets were to be applied theoretically to each emissions category, unless international action is taken to reduce emissions from international shipping lines, additional reductions in greenhouse gas emissions in this category to the comparatively very low levels of 1990 will not be feasible.



Off-road Equipment and Vehicles

- In 2006, off-road equipment and vehicles generated approximately 1.3 MMT CO₂E.
- The BAU 2020 forecast estimate is 1.6 MMT CO₂E, approximately 23% greater than the 2006 estimate.

Rail

- In 2006, the rail category generated approximately 0.3 MMT CO₂E, about 1% of the total County GHG emissions.
- The BAU 2020 forecast estimate is 0.4 MMT CO₂E, approximately 35% greater than the 2006 estimate.

2. Greenhouse Gas Emissions from Civil Aviation

Eleven airports in San Diego County, including the region's main commercial and international airport at Lindbergh Field, constitute the sources of greenhouse gas emissions in the aviation category. The San Diego County Regional Airport Authority (SDCRAA) operates and controls the Lindbergh Field International Airport and a second smaller commercial airport, the McClellan-Palomar airport. Two small landing strips, Montgomery Field and Brown Field, are owned and operated by the City of San Diego. An additional nine general aviation (private and military) airstrips are operated by the County of San Diego: the Agua Caliente airport, the Borrego Valley airport, the Fallbrook airport, the Jacumba airport, the Ocotillo airport, the Ramona airport and Gillespie Field Airport. Only emissions from commercial aviation operations at the San Diego International Airport are included in this inventory, primarily due to the lack of data from the McClellan-Palomar Airport at the time of writing. However, the number of commercial flights from the San Diego Airport (more than 500 a day) dwarfs the daily 8 commercial flights departing the McClellan-Palomar Airport, so the estimate presented here would not change significantly if data from this airport were included.

Emissions sources considered by the California Air Resources Board Greenhouse Gas Inventory (CARB GHG inventory) to constitute the civil aviation category are:

1. Emissions from the combustion of jet fuel and aviation gasoline⁴ used in commercial operations
2. Emissions from the combustion of natural gas used in airport ground transport operations
3. Emissions from the combustion of jet fuel used in international aviation

However, international aviation emissions are itemized separately and excluded from the final aviation category emissions in the CARB GHG inventory. The CARB GHG inventory further distinguishes between intrastate (within California) and interstate (within the US) emissions and includes only the intrastate civil aviation emissions. While this report retains this distinction for San Diego County, the two emissions sub-sources (intrastate and interstate) are added together to estimate the total aviation emissions level. The project team included interstate emissions because these are the largest and fastest growing portion of the greenhouse gas emissions from aviation in this County. In 1990, the intrastate emissions from San Diego constituted less than 20% of the total civil aviation category emissions. In 2006, this percentage had decreased to less than 10% and in 2020, the percentage is projected to be about 6% of the total. Excluding interstate emissions would significantly underestimate GHG emissions from aviation in the County. All other sources of airport and aviation emissions, such as those caused by electricity consumption, off-road vehicles and stationary sources, with the exception of natural gas powered ground transportation, are included in other categories of the San Diego County Greenhouse Gas Inventory.

Figure 2 shows the total greenhouse gas emissions in San Diego County from the aviation category, which is the sum of jet fuel, aviation gasoline, and natural gas combustion emissions. Figure 3 shows the breakdown of the total into interstate and intrastate components.

Emissions from civil aviation in San Diego County constitute a small but increasing percentage of statewide emissions from this category. Between 1990 and 2004, the contribution of San Diego County to the California total aviation category emissions increased from 4.9% to 7.7%.

2.1. Greenhouse Gas Emissions from Combustion of Jet Fuel

To determine the amount of greenhouse gas emissions from the combustion of jet fuel, the project team used two different methods and took the average, as shown in Figure 4. In the first method, we calculated emissions based on jet fuel-sold data provided by the two suppliers of jet fuel at the San Diego International Airport. The jet fuel data provided by one of the suppliers was separated into commercial and private use, whereas the other supplier reported that its jet fuel was sold only for commercial purposes. Because not all aircraft fuel in San Diego County, we used a second method using the miles departing San Diego International Airport to obtain an upper limit for civil aviation emissions from the county.⁵ The true emissions levels will be somewhere between the results of these two methods. Thus the average of the two methods as presented here for the county provides a good representation of the jet fuel emissions from the region.

Figure 2. Total GHG Emissions from Domestic Aviation, San Diego County

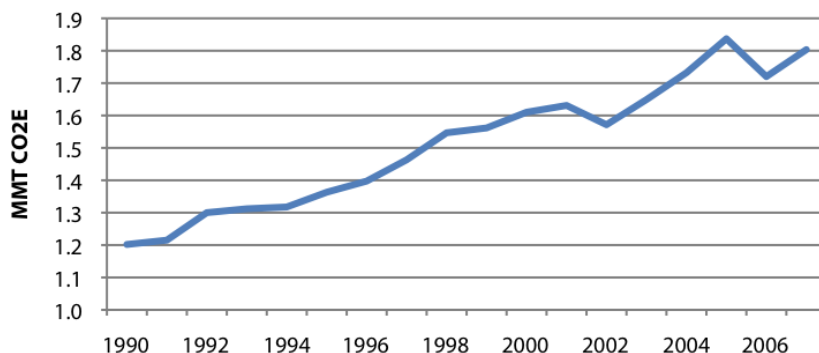


Figure 3. GHG Emissions from Intrastate and Interstate Flights, San Diego County

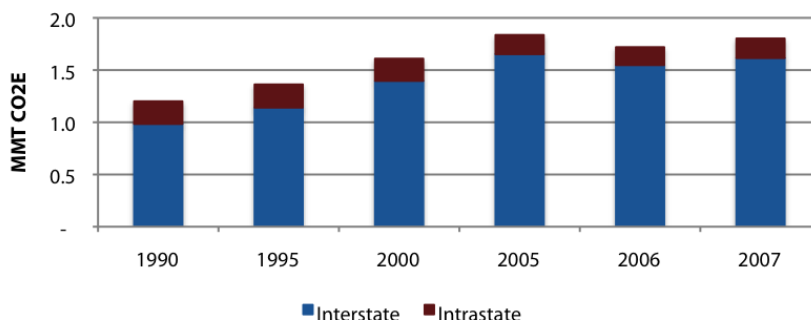
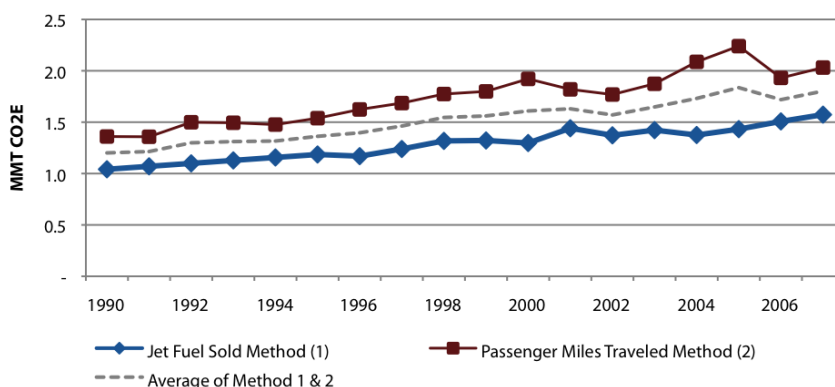


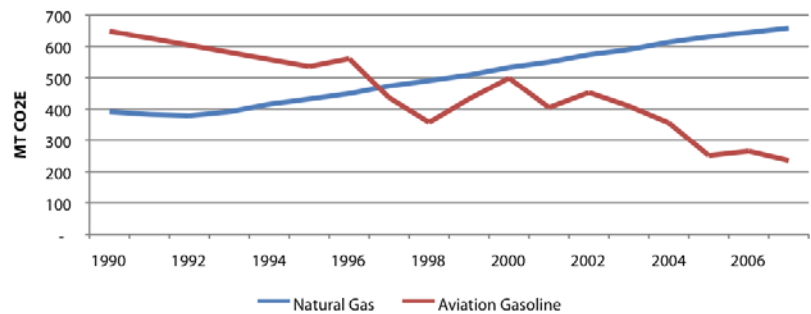
Figure 4. Methods to Determine GHG Emissions from Jet Fuel Use at San Diego Airport



2.2. Greenhouse Gas Emissions from Aviation Gasoline and Natural Gas

Aviation gasoline is a high-octane gasoline used for aircraft and racing cars. The aviation gasoline sold at the San Diego International Airport is for private aviation and has decreased from 66,052 gallons in 1996 to 27,729 gallons in 2007. Concerns over the lead content of aviation gasoline⁶ and its associated cost make it likely that aviation gasoline will not be used in San Diego County by 2015.⁷ Natural gas is used for ground transportation at San Diego International Airport. The volume of natural gas use at the airport increased from 9.5 million cubic feet in 1990 to 52.5 million cubic feet in 2006.⁸ Figure 5 presents the trends in emissions from aviation gasoline and natural gas in the civil aviation category.

Figure 5. GHG Emissions from Aviation Gasoline and Natural Gas, San Diego Airport



2.3. Emissions Projections

The SDCRAA published an Aviation Activity Forecast in June 2004 that projects growth scenarios through 2030 based on regional population and economic growth⁹ including the number of enplanements¹⁰ from the San Diego airport (Figure 6).¹¹

The project team used the SDCRAA forecasts of domestic enplanements as the basis for projecting greenhouse gas emissions. The 2006 emissions are 1.7 MMT CO₂E, approximately 0.5 MMT CO₂E (43%) above 1990 levels. Based on the projected unconstrained airport forecast for 2020, the BAU emissions for the whole category will be approximately 2.6 MMT CO₂E, an increase of 53% (Figure 7).

Figure 6. Domestic Enplanements San Diego International Airport

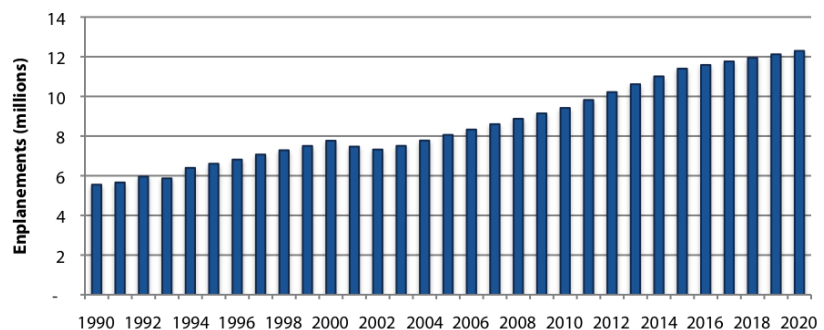
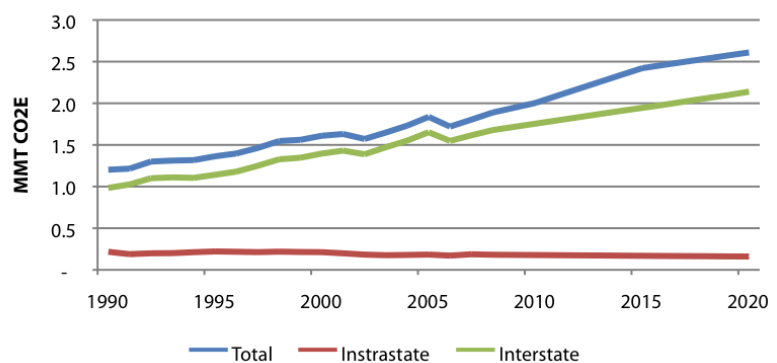
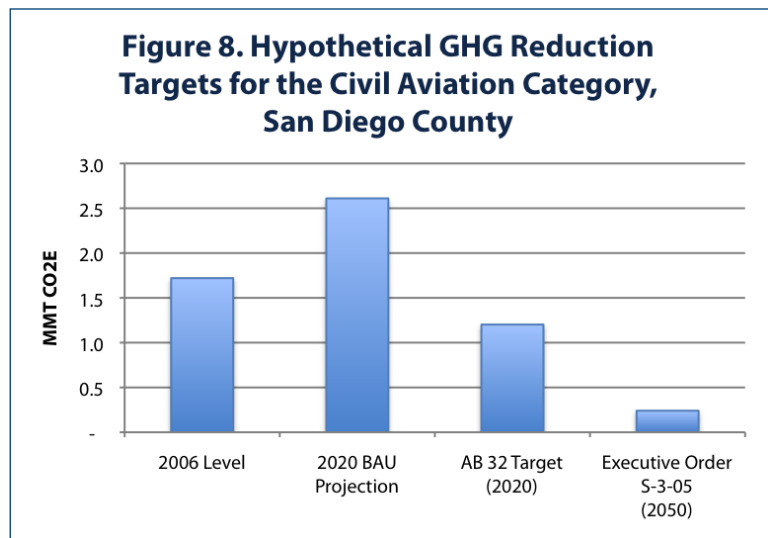


Figure 7. Total GHG Emissions from Domestic Aviation, San Diego County



2.4. Emissions Reduction Targets

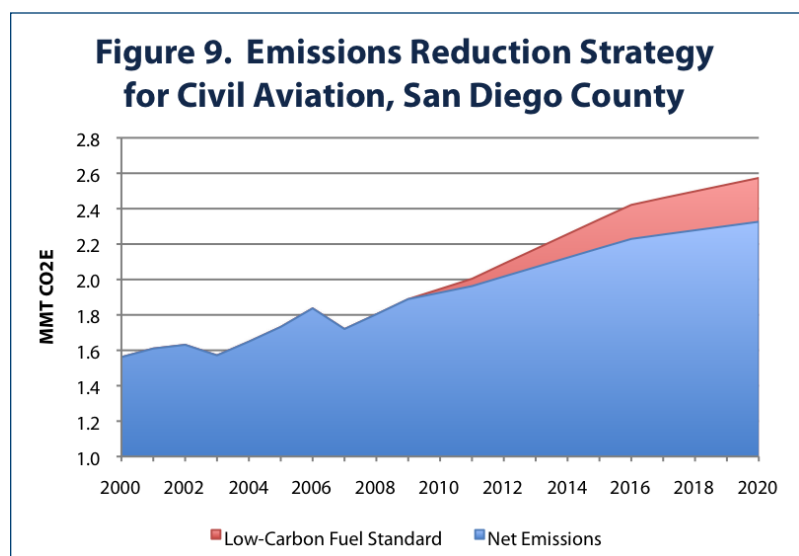
In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide greenhouse gas emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County and to each emitting category. To meet the targets established by AB 32, the San Diego region theoretically would have to reduce the projected emissions in the civil aviation category by 1.4 MMT CO₂E in 2020 to reach 1990 levels – a 54% reduction.



In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for greenhouse gas emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, total emissions from the civil aviation category would have to be reduced to 0.2 MMT CO₂E – a reduction of 2.4 MMT CO₂E (91%) below the 2020 business-as-usual forecast and 0.9 MMT CO₂E (88%) below 2006 levels. Figure 8 compares 2006 emissions levels, 2020 business-as-usual projections, AB 32 and Executive Order S-3-05 targets.

2.5. Potential Emissions Reduction Strategies

The project team developed emissions reduction strategies for each emissions category to determine if it is possible to meet the theoretical targets under AB 32. Where possible these strategies are based on federal, state, county, city level policies. Similar to other transportation categories that rely on fossil fuel combustion, emissions from civil aviation are driven by air miles traveled, the amount of fuel used, and the type of fuel used. The strategy presented here focuses on the carbon intensity of fuel. A low-carbon fuel standard for jet fuel could potentially achieve a reduction on aircraft emissions. Because of the global



projected large increase in commercial aviation by 2030, research is underway by the aircraft industry to develop fuel with a lower carbon intensity than jet fuel.¹² A potential reduction strategy may be achieved by

applying the same type of low-carbon fuel standard as for on-road transport. A 10% decrease in emissions may be effected by such a reduction in carbon intensity of jet fuel by 2020 as well as further improvements in engine fuel efficiency. This could potentially result in a reduction of 0.26 MMT CO₂E by 2020, as shown in Figure 9. This falls short of the hypothetical AB 32 target reduction for this category.

2.6. Aviation Methodology

The project team calculated total greenhouse gas emissions from aviation activity using two different methods: a fuel-based method using actual and estimated jet fuel and aviation gas data, and another top-down approach using a combination of national and local data to estimate jet fuel use.

The two main suppliers of jet fuel and aviation gas in the region provided data on the amount of these fuels sold at San Diego International Airport. One supplier provided data from 1996-2007, the other from 1997-2007. The project team back cast values for 1990-1996 using linear regression based on this data (Method 1). Because the jet fuel sold does not reflect the emissions caused by departing flights that do not fuel up during a stopover in San Diego, an additional top-down method was used to estimate jet fuel use and therefore provide an upper limit for emissions. In this Method 2, we used passenger miles flown, separated into interstate and intrastate miles, in combination with average aircraft fuel efficiency data to obtain jet fuel use estimates.

Jet Fuel Emissions Using Fuel Sold (Method 1)

The annual jet fuel data obtained from the San Diego International Airport Lindbergh Field suppliers represents the jet fuel sold to commercial operations and some private flights departing from San Diego. As mentioned above, these data do not represent all departing flights, since some of which may not have refueled while stopping over in San Diego; therefore, calculations based solely on fuel sold to flights departing from San Diego will underestimate greenhouse emissions associated with flights departing from San Diego. In addition, these jet fuel data represent only fuel sold to the San Diego International Airport and not the jet fuel used by any of the other airports, which was not available at the time of writing. This represents an additional data gap that causes an underestimate of the emissions from aviation activities. On the other hand, Lindbergh Field represents over 95% of the commercial flights from the County.

The fuel sold method is the ideal method of GHG emissions estimation provided this information is available and each county or region uses this same method. The equation used to calculate the emissions is:

greenhouse gas emissions = fuel gallons * emissions factor,

where the emissions factors for commercial jet fuel and aviation gasoline were obtained from the CARB GHG inventory (Table 2).

Table 2. Emissions Factors Used in Civil Aviation Category¹³

Fuel type	Methane (grams/gallon)	Nitrous Oxide (grams/gallon)	Carbon Dioxide (grams/gallon)
Jet fuel	0.3	0.3	9,570
Aviation gasoline	7.1	0.11	8,310

Emissions depend on the number and type of aircraft operations, the types of fuel used, the length of flight and the times spent at each stage of the flight but the rough composition of any aircraft emissions are 70% CO₂, a little less than 30% water and the rest consists of the trace GHGs. Emissions factors differ slightly at each stage of engine use. The emissions factors for CO₂, CH₄ and N₂O from fuel combustion provided in Table 2 take into account these differences as well as the heat content of the fuel and may therefore be used in calculations carried out for San Diego County.

The CO₂ equivalent emissions are calculated by multiplying the above-calculated emissions by the respective global warming potential of 21 for methane and 310 for nitrous oxide.¹⁴

Passenger Miles Traveled Method (Method 2)

In this method, the passenger miles flown out of San Diego International Airport were used in combination with fleet energy intensity data to estimate fuel use. This method would capture the emissions due to passenger flights which do not fuel up in San Diego and would be appropriate for cases in which fuel data are sparse or if the purpose is to allocate passenger flight emissions to the source, or attribute emissions regionally. As emissions due to all departing passenger flights are accounted for, including flights that do not fuel here, emissions are necessarily greater than with Method 1. However, because this method is based on passenger activity, emissions due to cargo (mail and freight) flights are not captured, whereas Method 1 includes all types of domestic commercial flights.

Passenger miles traveled from San Diego International Airport were extracted from the Bureau of Transportation Statistics Department (BTS RITA) database for each year from 1990 to 2007.¹⁵ The energy

intensity for a range of the total US commercial aircraft fleet over the past 20 years is also available in the same database and is shown in modified version in Table 3.

Table 3. US Aircraft Fleet Fuel Intensity Data

Year	Passenger Miles (millions)	Fuel Consumed (million gallons)	Intensity (mpg)
1960	30,557	1,954	16
1965	51,887	3,889	13
1970	104,147	7,857	13
1975	131,728	7,558	17
1980	200,289	8,519	24
1985	270,584	10,115	27
1990	340,231	12,323	28
1991	332,566	11,506	29
1992	347,931	11,763	30
1993	354,177	11,959	30
1994	378,990	12,384	31
1995	394,708	12,672	31
1996	425,596	13,217	32
1997	450,612	13,563	33
1998	463,262	13,335	35
1999	488,357	14,402	34
2000	516,129	14,845	35
2001	486,506	14,017	35
2002	482,310	12,848	38
2003	505,158	12,959	39
2004	557,893	13,623	41
2005	584,996	13,789	42
2006	591,834	13,458	44

Note that the US fleet fuel efficiency has improved by more than 60% since 1960. Using the miles per gallon information from Table 3, the project team calculated an energy intensity or fuel efficiency range per passenger mile of 0.036 gallons in 1990 to 0.023 gallons in 2006. Assuming the same fleet mix in San Diego as in the United States,¹⁶ multiplication of the fuel efficiency by the passenger miles gives jet fuel consumption for all domestic passenger departures from San Diego as follows:

Fuel efficiency (gallons/passenger mile) * passenger miles = gallons total.

As the miles traveled data can be separated into intrastate and interstate flights, this method allows calculation of the jet fuel used for intrastate versus interstate passenger flights and therefore a similar separation of emissions associated with each. The fuel use calculated using this method is presented in Table 4.

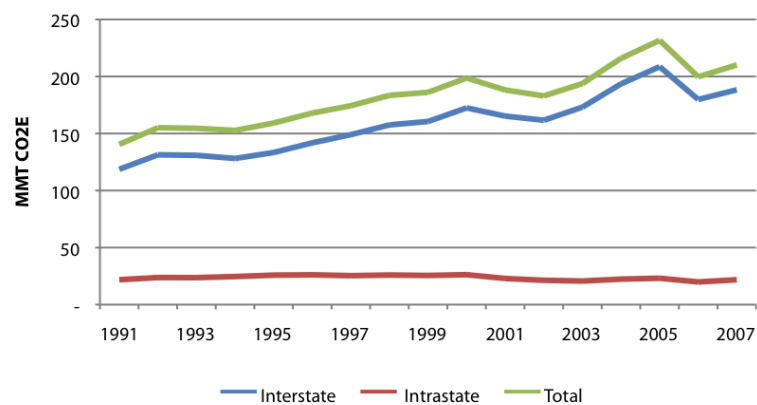
The results of Method 2 show a trend in the last 15 years towards decreasing intrastate miles and increasing interstate miles (Figure 10). Therefore in these years, the driving force for aviation emissions has been interstate miles flown.

The emissions calculated by this method are necessarily greater than that calculated by the fuel sold (Method 1) since not all aircraft fuel in San Diego. With this method, it is possible to distinguish between intrastate and interstate emissions, which is not possible with the jet fuel sold method, as the data provided could not be separated. It is clear that intrastate emissions are significantly lower than interstate emissions, and that intrastate flights are the driving force for civil aviation emissions.

Table 4. Fuel Use Based on Passenger Miles Departing San Diego (Method 2)

Year	Intrastate	Interstate	Total
1991	21,817,877	118,638,261	140,456,138
1992	23,737,743	131,318,319	155,056,062
1993	23,660,905	130,887,314	154,548,219
1994	24,603,035	128,113,028	152,716,063
1995	25,833,708	133,335,337	159,169,045
1996	26,102,819	141,834,122	167,936,941
1997	25,378,007	148,982,055	174,360,062
1998	25,930,321	157,532,786	183,463,107
1999	25,561,289	160,538,370	186,099,659
2000	26,230,055	172,465,508	198,695,563
2001	22,913,675	165,256,946	188,170,621
2002	21,323,554	161,645,578	182,969,133
2003	20,653,653	173,115,756	193,769,409
2004	22,338,965	193,519,222	215,858,187
2005	23,143,532	208,542,794	231,686,326
2006	19,863,520	179,848,234	199,711,754
2007	21,812,737	188,311,390	210,124,127

Figure 10. Fuel Use Based on Passenger Miles Departed from San Diego Airport



The difference in emissions between the fuel-sold method (Method 1) and the passenger miles departed method (Method 2) ranges from 300,000 to 800,000 metric tons, or from 30-50% of the emissions based on the fuel sold (Figure 11).

Although the emissions trend is positive and rising in both cases, the fuel sold method indicates a slower rate of increase than the passenger miles method, resulting in a gradually increasing gap between the two. One possible explanation for this difference, which has not been further examined, may be a tendency to reduce fueling at San Diego International Airport.

Because of the large difference in results of the two methods, an average of the results of the two methods reduces the error in the emissions estimates. The average values differ from the results of either method by about 20%. These averaged jet fuel emissions were used in the total aviation category emissions presented above.

Aviation Gasoline and Natural Gas

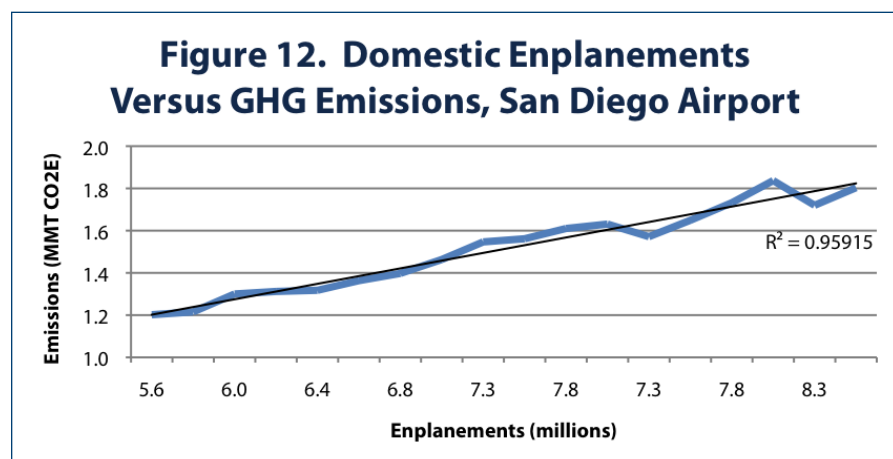
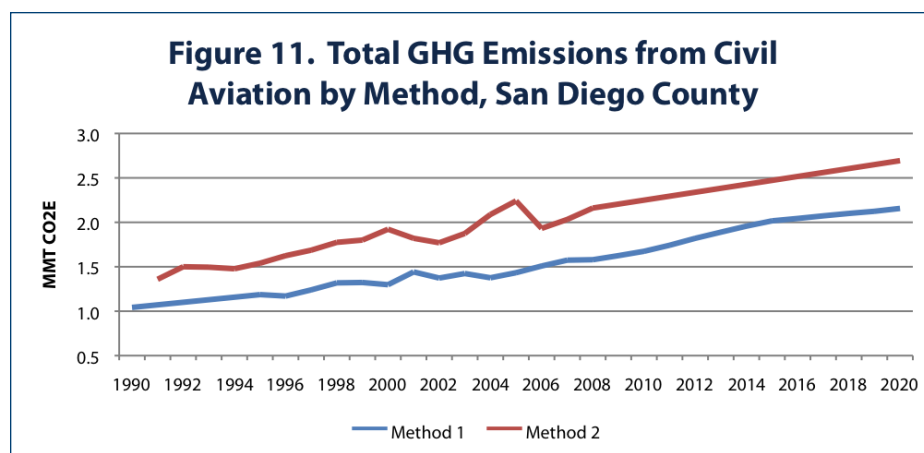
In addition to jet fuel, the project team calculated the greenhouse gas emissions from aviation gasoline and natural gas. Only one of the fuel suppliers sells aviation gasoline at the San Diego International Airport. This data was available from 1996-2007. Only the fuel-sold method (Method 1) could be used to calculate emissions as the miles departed data for flights using aviation gasoline is not available.

Natural gas is also used in the aviation category for ground transportation purposes. The project team used data provided by the San Diego County Air Pollution Control District (APCD) for natural gas use at San Diego International Airport¹⁷ together with Method 1 to calculate emissions from natural gas.

Calculation of Forecasts

The calculation of the emissions forecast was based on the trend relationship between total category emissions and domestic enplanements (Figure 12).

A potential strategy to reduce aviation emissions is to use a low carbon fuel standard in the same way as is expected for road vehicles. Such a low



carbon jet fuel strategy, as well as further improvements in aircraft engine fuel efficiency, applied to the total category emissions, can be seen as a 10% reduction in the emissions to obtain the potential reduction wedge shown in Figure 8.

Limitations

The estimated 1990 baseline emissions level for San Diego County is not directly comparable to the CARB statewide greenhouse gas inventory results for the civil aviation category because CARB does not include interstate emissions. CARB calculations use the fuel-sold method; aircraft fuel sold in San Diego does not fuel all aircraft leaving the region, therefore this method is not as appropriate at the county level. In addition, it was not possible to obtain fuel use or commercial aircraft miles departing from other County airports, namely the McClellan Airport. This would give rise to a slight underestimation from civil aviation in the County.

A further methodological limitation is that an increasing percentage of the jet fuel data provided by one of the fuel suppliers is for private jets. On the other hand, between 1996 and 2007, this supplier has sold an average of 6% of the total jet fuel to the airport. Also, it was not possible to obtain fuel use data for private jets at other airports, which make up the majority of flights from the McClellan and all other county airports. Therefore, it is not possible to estimate the total emissions caused by private aircraft in the county, although we did include in the total estimate the relatively small volume of jet fuel sold for private aviation at the San Diego International Airport.

3. Greenhouse Gas Emissions from Water-Borne Navigation

All types of water-borne navigation in the County contribute to regional greenhouse gas emissions in this category, but only the largest sources of shipping emissions relating to the Port of San Diego (Port), including those ships that pass through the County water lines, were used for this inventory. The Port serves as a transshipment facility for San Diego, Orange, Riverside, San Bernardino and Imperial Counties, northern Baja California, Arizona, and other points east of California. The Port owns and has jurisdiction of the marine terminals at Tenth Avenue, the National City Marine Terminal and the B Street Cruise Ship Terminal. The Tenth Avenue terminal receives refrigerated commodities, fertilizer, cement, bulk commodities and forest products cargo ships. The National City Marine Terminal is mainly an auto terminal, but also has berths that handle forest products. The B Street Cruise Ship terminal is equipped to handle cruise lines.

The specific emissions sources included in this inventory, which are based on the categories used in the California Air Resources Board (CARB) statewide greenhouse gas inventory, are as follows:

- Ocean Going Vessels (OGVs) – these include auto carriers, bulk carriers, passenger cruise vessels, general cargo vessels, refrigerated vessels (reefers), roll-on roll-off Vessels (RoRo) and tankers for bulk liquids, which call at the Port of San Diego as well as those passing through.
- Harbor Craft – these include tugboats, ferries, and commercial fishing vessels.

With the exception of military vessels, all other categories that belong to emissions sources from the Port, as well as indirect emissions caused by electricity use, form part of other categories of this inventory as follows:

- Off-road cargo handling equipment (included in the Off-Road Equipment and Vehicles Section below)

- Railroad locomotives (included in the Rail Section below)
- On-road heavy duty diesel vehicles (Included in the On-Road Transportation Section)
- Stationary sources (combustion sources for electricity generation included in the Electricity Section)
- Recreational vessels (included to some extent in the Off-Road Equipment and Vehicles Section below)
- Non-port owned vessels and facilities (not included)
- Military vessels (not included)
- Other energy use such as electricity and natural gas use (included in the Electricity and Natural Gas categories)

The activities that cause OGV and harbor craft emissions are operations within the designated waters, transit and maneuvering inside the San Diego Bay, and hotelling.¹⁸ The designated zone within which emissions are associated with the County is bordered to the south by the U.S.-Mexico international border extended over water, to the north by the San Diego County line extended over water and to the west within the internationally agreed 24-mile territorial and contiguous zone.

The methodology for greenhouse gas calculations by CARB and other entities requires the use of emissions factors based on the fuel type, the engine type and operating mode, the time spent in each mode –transit, anchorage, maneuvering and berthing (hotelling), engine rated power, engine load factors, fuel consumption of the engine types and the number of port calls of each type of OGV. While port call data is available from maritime organizations, the only other data available within the timeframe of this inventory was the total amount of fuel sold for the San Diego Port which includes fuel sold for international shipping outside of the 24 nautical mile boundary used for the inventory. Within the time frame of this project, it was not possible to produce ground-up calculations for shipping emissions from 1990. Instead, emissions data was provided by CARB from its 2007 updated statewide emissions data and scaled to the San Diego region.

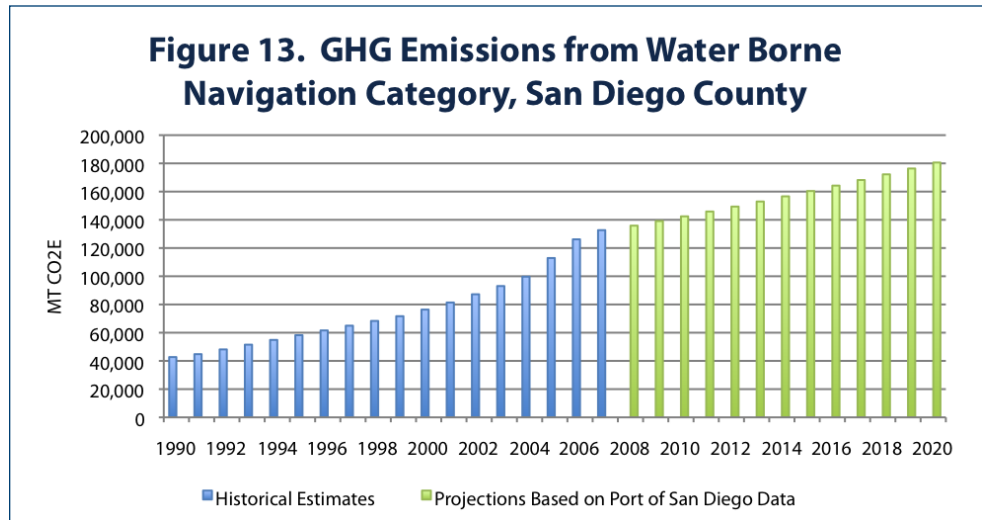
The responsibility for traditional pollutant emissions control falls to the San Diego Air Pollution Control District (APCD), the Air Resources Board and the California Environmental Protection Agency (CA-EPA). The following proposed regulatory measures will have the effect of reducing greenhouse gas emissions from OGVs and have been taken into account in the forecasts for shipping emissions provided by CARB:

- CARB 2005 regulation for low sulfur fuel (0.5% S from 2007, <0.1% from 2010) for auxiliary engines within 24 nautical miles (nm)
- 2007 Shore Power Regulation (Res 07-57), which aims to reduce emissions from diesel auxiliary engines on container ships, passenger ships, and refrigerated cargo ships while at-berth at a California Port.

3.1. Historical and Projected Emissions

Shipping emissions have shown a gradual increase between 1990 and 2006 (Figure 13). The 1990 baseline estimate for San Diego County shipping emissions is 42,700 metric tons CO₂E. The 2006 emissions are estimated at 126,200 metric tons CO₂E, 0.4% of the total countywide emissions.¹⁹ The projected 2020 level for OGVs and harbor craft is estimated to be 180,600 metric tons CO₂E, a 43% increase over 2006 levels.

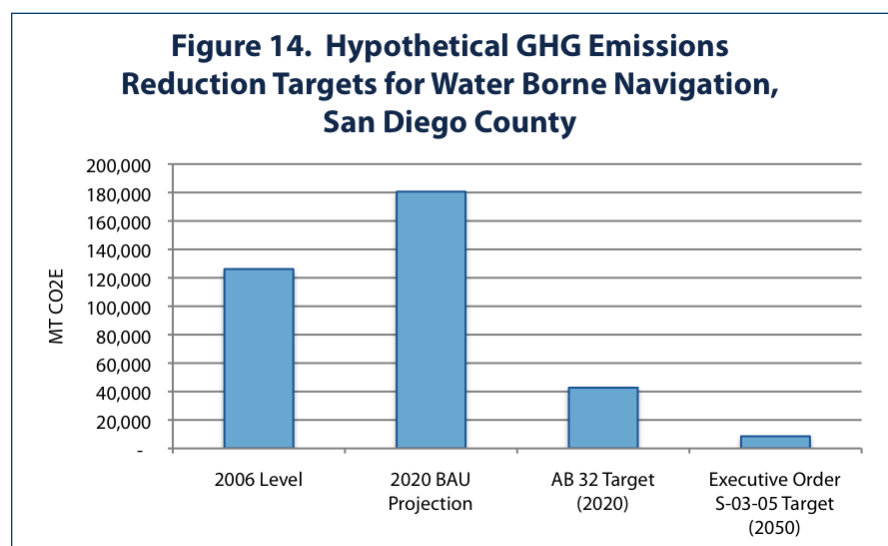
This projection includes the emissions reductions expected from the 2007 Shore Power Regulation and the 2005 Auxiliary Engine Regulation.



3.2. Emissions Reduction Targets

In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide greenhouse gas emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County and to each emitting category. To meet the theoretical targets established by AB 32, the San Diego region would have to reduce projected water-borne navigation emissions by approximately 138,000 MT CO₂E to reach 1990 levels – a 76% reduction.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for greenhouse gas emissions reductions. It seeks to reduce emissions to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to this category



of the San Diego County, total emissions from water-borne navigation would have to be reduced to approximately 9,000 MT CO₂E – a reduction of more than 95% below the 2020 business-as-usual forecast and about 93% below 2006 levels. Figure 14 compares 2006 emissions levels, 2020 business-as-usual projections, AB 32 and Executive Order S-3-05 targets.

3.3. Emissions Reduction Strategies

The 2007 Shore Power Regulation is already predicted to reduce carbon dioxide equivalent emissions by 50% by 2020.²⁰ This is taken into account in the CARB-based San Diego county forecast for OGVs, and therefore in the above numbers and forecasts. The 2005 auxiliary engine regulation is also taken into account but is not expected to contribute significantly to the reduction because its purpose is mainly traditional air pollution reduction. Given the already very low relative 2020 level, which constituted less than 1% of the region's total greenhouse gas emissions 2006, it seems unlikely that further significant reductions can be expected from this category.

Ninety-five percent of the OGVs calling at the port of San Diego are foreign flagged, and more than 60% of the vessels depart for international ports. Therefore the degree of local, state and national control over shipping emissions beyond what has already been adopted is limited.

3.4. Methodology

The basic equation used by CARB for estimating emissions from OGVs is:

$$E_{y, t, om, e} = \epsilon \text{Pop}_{t, om, e} * EF_{e, om, f} * Hrs_{om, t} * VP_{om, t} * \%Load_{om, t}$$

where

E = pollutant specific emissions (tons per year of NO_x, HC, CO₂, SO₂, and diesel PM)

Pop = population of ocean-going vessels by vessel type

EF = emissions factor by engine type, operating mode, and fuel (units of g/kw-hr)

Hrs = average annual use in hours by operating mode and vessel type

VP = average power by operating mode and vessel type

% Load = average engine load by operating mode and vessel type

y = inventory year

om = operating mode (transit, maneuvering, hotelling)

t = vessel type (auto, container, bulk cargo, etc.)

f = fuel (HFO or MGO/MDO)

e = engine type

The emissions factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). The emissions factors used by CARB are provided in the Tables 5-9 below.²¹

Table 5 Main Engine Emissions Factors, Transit Mode (g/kW-hr)

Engine Speed	Fuel	CH ₄	CO	CO ₂	NO _x	PM ₁₀	PM _{2.5}	ROG	SO _x
Slow	Marine Distillate (0.1% S)	0.07	1.10	588	17.0	0.25	0.35	0.78	0.36
Slow	Marine Distillate (0.5% S)	0.07	1.10	588	17.0	0.38	0.35	0.78	1.90
Slow	Heavy Fuel Oil	0.08	1.38	620	18.1	1.50	1.46	0.69	10.50
Medium	Marine Distillate (0.1% S)	0.08	1.10	645	13.2	0.25	0.35	0.65	0.40
Medium	Marine Distillate (0.5% S)	0.08	1.10	645	13.2	0.38	0.35	0.65	2.08
Medium	Heavy Fuel Oil	0.09	1.10	677	14.0	1.50	1.46	0.57	11.50
High	Marine Distillate (0.1% S)	0.08	1.10	645	12.1	0.25	0.35	0.65	0.40
High	Marine Distillate (0.5% S)	0.08	1.10	645	12.1	0.38	0.35	0.65	2.08
High	Heavy Fuel Oil	0.09	1.10	645	12.7	1.50	1.46	0.23	11.50

Table 6 Main Engine Emissions Factors, Maneuvering Mode (g/kW-hr)

Engine Speed	Fuel	CH ₄	CO	CO ₂	NO _x	PM ₁₀	PM _{2.5}	ROG	SO _x
Slow	Marine Distillate (0.1% S)	0.07	1.10	588	17.0	0.25	0.35	0.78	0.36
Slow	Marine Distillate (0.5% S)	0.07	1.10	588	17.0	0.38	0.35	0.78	1.90
Slow	Heavy Fuel Oil	0.08	1.38	620	18.1	1.50	1.46	0.69	10.50
Medium	Marine Distillate (0.1% S)	0.08	1.10	645	13.2	0.25	0.35	0.65	0.40
Medium	Marine Distillate (0.5% S)	0.08	1.10	645	13.2	0.38	0.35	0.65	2.08
Medium	Heavy Fuel Oil	0.09	1.10	677	14.0	1.50	1.46	0.57	11.50
High	Marine Distillate (0.1% S)	0.08	1.10	645	12.1	0.25	0.35	0.65	0.40
High	Marine Distillate (0.5% S)	0.08	1.10	645	12.1	0.38	0.35	0.65	2.08
High	Heavy Fuel Oil	0.09	1.10	645	12.7	1.50	1.46	0.23	11.50

Table 7 Auxiliary Engine Emissions Factors, Transit, Maneuvering, and Berthing (g/kW-hr)

Engine Speed	Fuel	CH ₄	CO	CO ₂	NO _x	PM ₁₀	PM _{2.5}	ROG	SO _x
Medium	Marine Distillate (0.1% S)	0.09	1.10	690	13.9	0.25	0.35	0.52	0.40
Medium	Marine Distillate (0.5% S)	0.09	1.10	690	13.9	0.38	0.35	0.52	2.10
Medium	Heavy Fuel Oil	0.09	1.10	722	14.7	1.50	1.46	0.46	11.10

Table 8 Auxiliary Boiler Emissions Factors (g/kW-hr)

Fuel	CH ₄	CO	CO ₂	NO _x	PM ₁₀	PM _{2.5}	ROG	SO _x
Marine Distillate (0.1% S)	0.03	0.20	970	2.0	0.13	0.78	0.11	0.57
Marine Distillate (0.5% S)	0.03	0.20	970	2.0	0.20	0.78	0.11	2.99
Heavy Fuel Oil	0.03	0.20	970	2.1	0.80	0.78	0.11	16.50

Table 9 Fuel Consumption by Engine Type (g/kW-hr)

Engine	Engine Speed	Mode	Fuel	Fuel Use Rate
Auxiliary	All	All	Marine Distillate	217
	All	All	Residual	227
Boiler	N. A.	All	Residual	305
Main	High	Transit	Residual	213
	Medium	Transit	Marine Distillate	203
	Slow	Transit	Marine Distillate	185
	Medium	Transit	Residual	213
	Slow	Transit	Residual	195
	High	Maneuvering	Residual	213
	Medium	Maneuvering	Marine Distillate	203
	Slow	Maneuvering	Marine Distillate	185
	Medium	Maneuvering	Residual	213
	Slow	Maneuvering	Residual	195

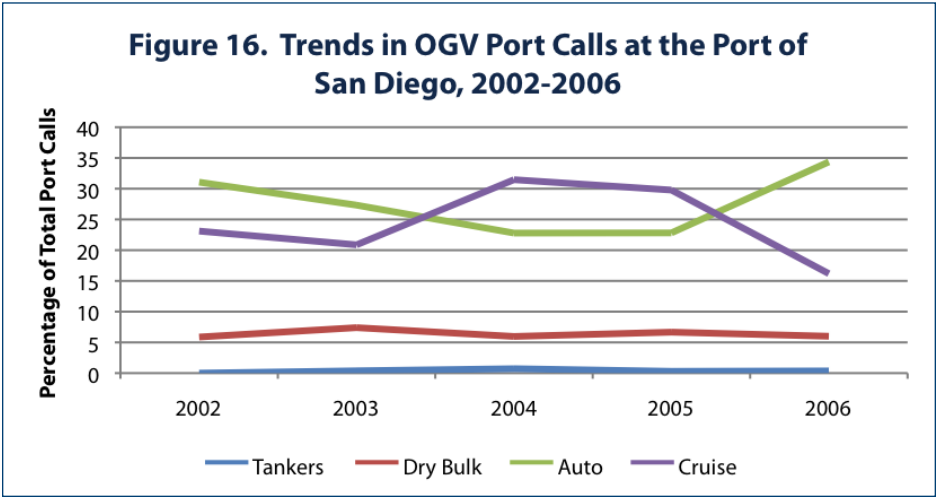
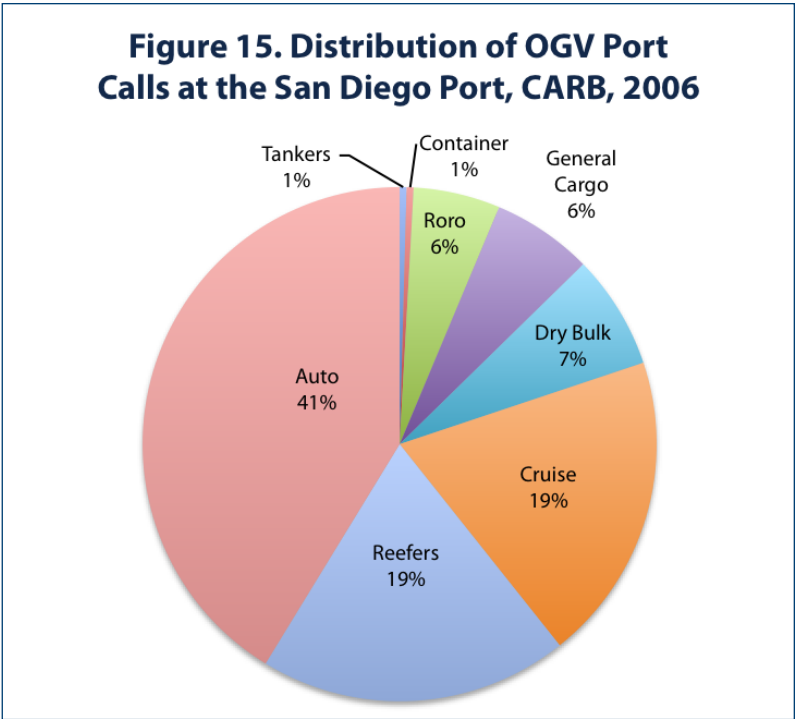
The above emissions factors are consistent with the emissions factors used by Starcrest in its Port emissions inventory of 2006.

The fuel consumption rates used by CARB for the different engines are given in Table 9. The equivalent values used by Starcrest were not available.

CARB assumed that the main engines and auxiliary boilers burned heavy fuel oil and that for auxiliary engines, 92% of cruise ships burned fuel oil and 8% distillate. For all other ships, the assumptions were 71% heavy fuel oil and 29% distillate. The equivalent information used by Starcrest was not available.

In their estimate, CARB used data from California Lands Commission for vessel population and number of port calls while berthing was obtained from the each California port. The vessel populations used by CARB are similar to that used by the San Diego Port Air Emissions Inventory 2007 (Figure 15).

Historical trend data for OGV port calls were not available from the Port of San Diego or CARB. According to OGV port call data available at the Maritime Administration from 2002-2006, none of the OGVs indicate an increasing trend, although auto ship calls increased from 2005 to 2006 (Figure 16). Cruise and auto ships make up the majority of the OGV calls in San Diego.



3.4.1. Harbor Craft Emissions

Harbor craft consist of tugboats, commercial and charter fishing boats, excursion boats, and government pilot boats. According to the 2007 CARB methodology on harbor craft emissions, as well as the Port Emissions Inventory (EI) of 2006, commercial and charter fishing boats make up the majority of the harbor craft. Although no data is available to compare the population of harbor craft in the same year, harbor craft vessel numbers data are available for 2004 and 2006 from the two sources, Starcrest and CARB. Large differences are observed between the number of harbor craft vessels provided in the Port EI for 2006 and the closest year for which CARB harbor craft numbers are available – 2004. The Port EI harbor craft population in 2006 was surveyed as 107 while the CARB 2004 allocation to the County was 307.²² The largest difference lay in the number of commercial fishing and excursion vessels with the CARB number at 260 and the EI number at 72.

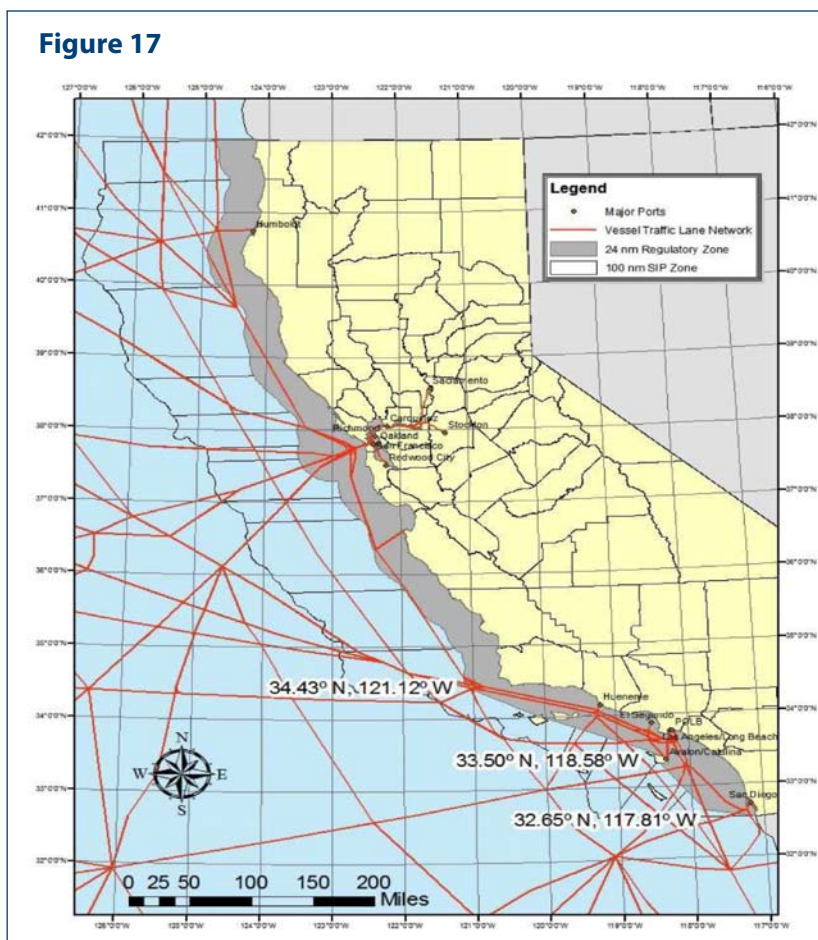
CARB also provided us with harbor craft emissions for the County and forecasts to 2020. However, the method of allocation of harbor craft and the emissions estimates from the state to county level may significantly overestimate harbor craft emissions, which would be of no significance in the calculation of the total state emissions for harbor craft. The allocation method does make a large difference when assigning emissions at the county level. We therefore based our harbor craft emissions (to a distance of 24 nm) on the one actual Starcrest EI survey obtained for 2006.²³ In that year harbor craft constituted 27% of the OGV number. With the assumption that the harbor craft use is proportional to the OGVs, the harbor craft emissions from 1990 to 2020 were estimated based on this percentage.

3.4.2. Scaling Statewide OGV Emissions to the County Level

OGV emissions for the County were provided by CARB scaled according to the operating hours in the various modes and calculated on the basis of the route taken between ports. OGVs passing through but not calling at the Port were also included. Vessel traffic lanes and routes (Figure 17) for California versus the San Diego County area as defined above were used for the route calculations.

3.4.3. Forecast Assumptions

The Port of San Diego provided the OGV traffic growth rates to 2020.²⁴ An average annual growth rate of 2.4% was calculated based on that data. The net registered tonnage by vessel type is proportional to engine power and therefore to the OGV emissions, and emissions forecasts were made on the basis of a 2.4% annual increase. For harbor craft, since only one GHG emissions value was available for the Port



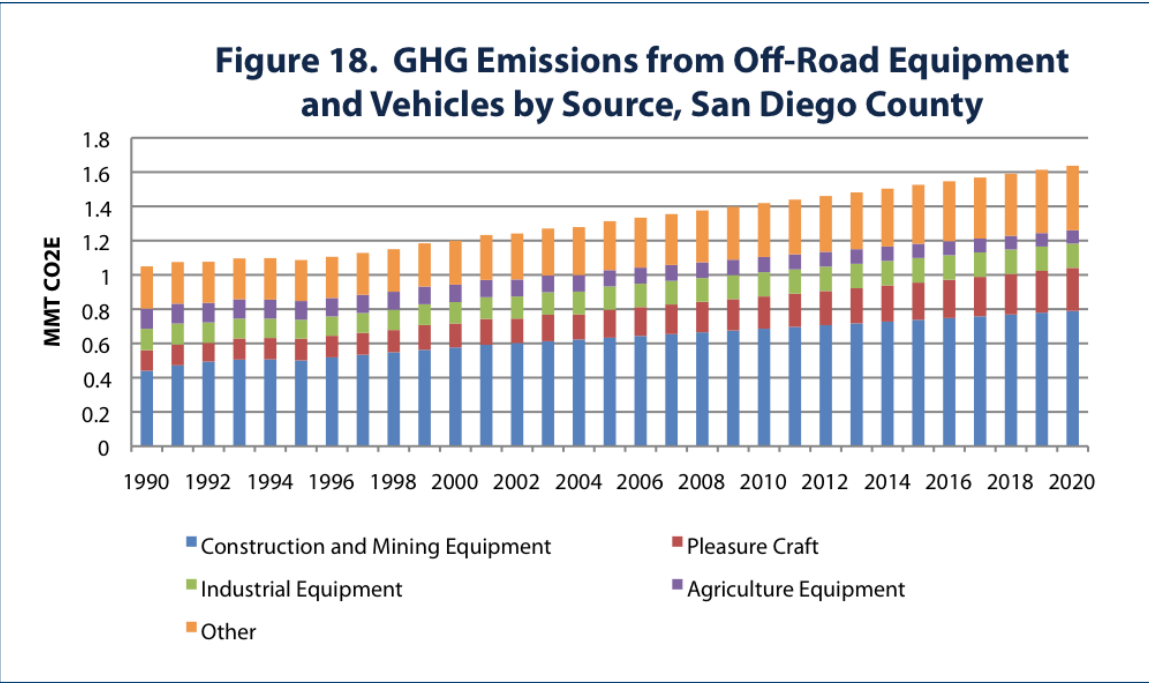
from the Starcrest inventory of 2007, the percentage this represented of the total OGV emissions (27%) was considered constant and used as an estimate for all harbor craft emissions from 1990 to 2020.

3.4.4. Limitations

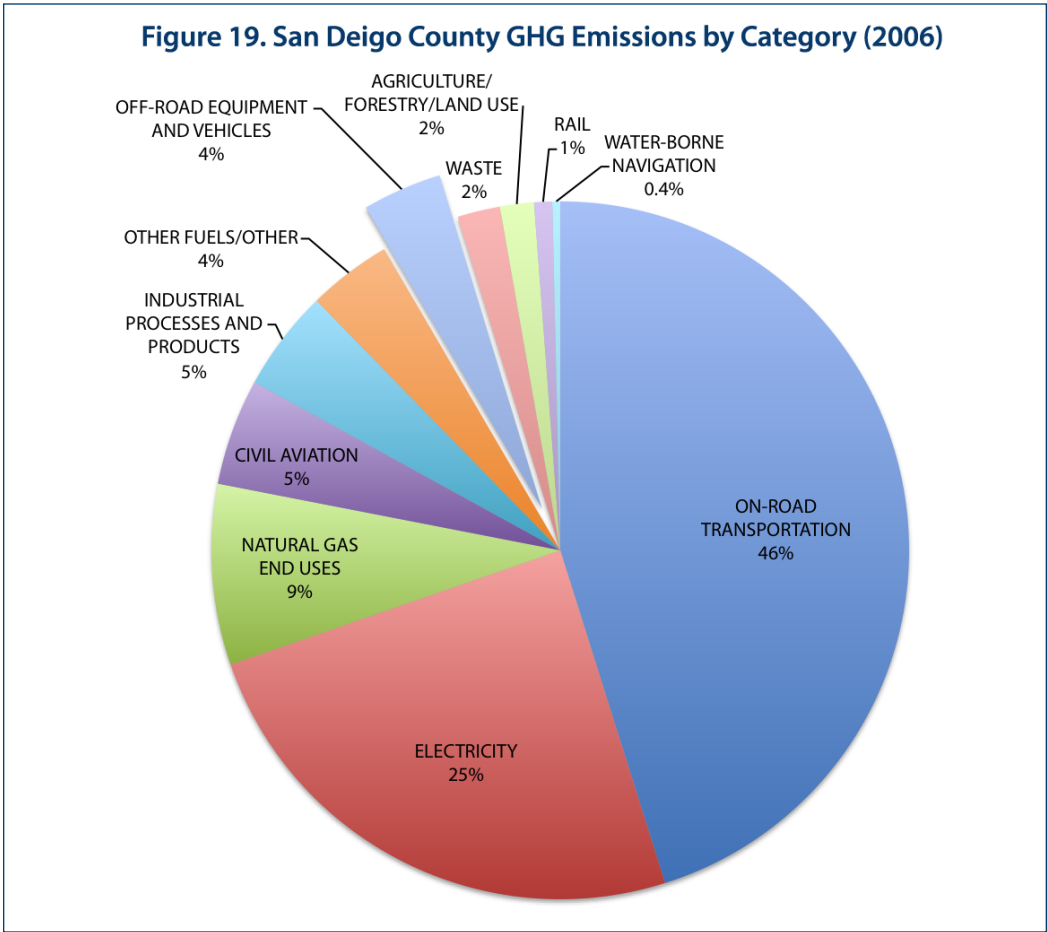
The main limitation is the lack of local survey data on harbor craft population except for the year 2006. Especially the number of commercial fishing boats may have varied significantly based on fluctuations in the fishery populations in the county waters since 1990 in place of the constant 27% of OGV assumption. However, as the total water-borne emissions in San Diego are small, these variations would be of little significance for the overall countywide greenhouse gas emissions.

4. Greenhouse Gas Emissions from Off-Road Equipment and Vehicle Emissions

In addition to emissions from on-road vehicles such as cars and trucks, off-road equipment and vehicles also emit greenhouse gases. This category includes the following equipment subcategories: agricultural, airport ground and support, construction and mining, dredging, entertainment, industrial, lawn and garden, light commercial, military, other portable machinery, pleasure craft,²⁵ railroad operations, recreational vehicles, and transport refrigeration units. The four largest sources of greenhouse gas emissions in this category are: construction and mining, industrial, pleasure craft, and agricultural. They accounted for about 80% of emissions from this category in 2006 and are expected to continue to dominate this category until 2020, as shown in Figure 18.

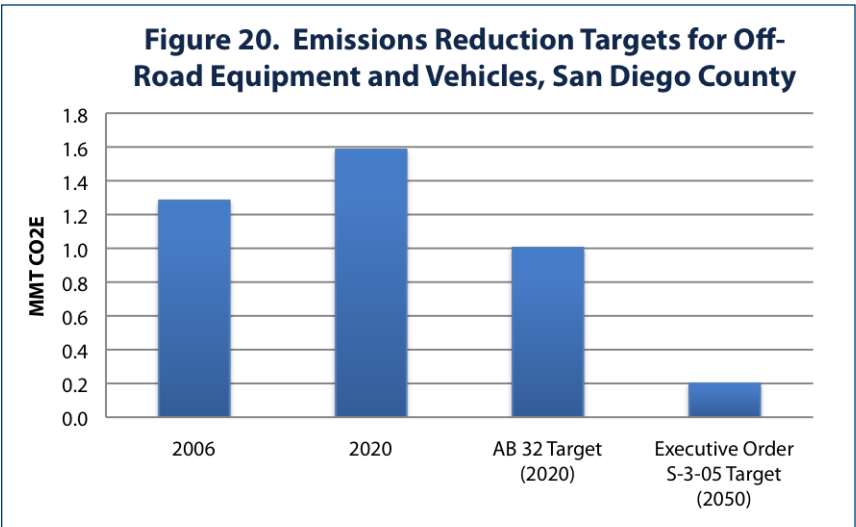


In 2006, the off-road equipment and vehicle category accounted for emissions of 1.3 MMT CO₂E, an increase of 28% above 1990 levels. Off-road emissions were about 4% of the total in San Diego County in 2006 (Figure 19). If current trends continue, annual emissions from this category will be 1.6 MMT CO₂E in 2020, an increase of 23% above 2006 levels.



4.1. Emissions Reductions Targets

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide emissions to 1990 levels by the year 2020. Even though it does not specify reduction targets for specific areas or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied



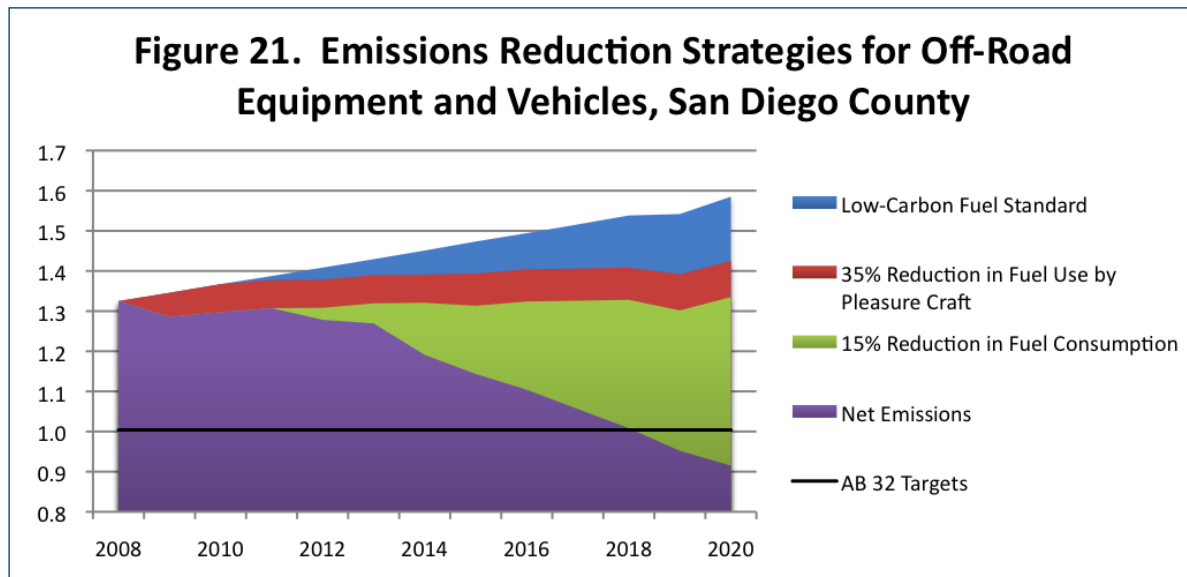
proportionally to San Diego County. To meet the targets established by AB 32, San Diego would have to reduce its projected business-as-usual 2020 annual emissions in this category by 0.6 MMT CO₂E or 37%.

Earlier, in 2005, Governor Schwarzenegger signed Executive Order S-3-05, which established long-term emissions reduction targets of 80% below 1990 levels by 2050. While this target is not law, it is generally accepted as the ideal toward which California regulations are aiming. Like AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, off-road equipment and vehicle GHG emissions would have to be 0.2 MMT CO₂E by 2050 - a reduction of 1.4 MMT CO₂E below the 2020 business-as-usual forecast. Figure 20 illustrates a comparison of GHG emissions reduction targets for AB 32 and Executive Order S-3-05.

4.2. Emissions Reductions Strategies

To reduce off-road equipment and vehicle emissions to 1990 levels by 2020, emissions from this category will have to be reduced by 0.6 MMT CO₂E below the business-as-usual 2020 forecast.

To illustrate how the region could achieve this, the project team developed several strategies and calculated how much each strategy could reduce emissions. The results were used to develop the reduction “wedges” illustrated in Figure 21. This approach was adapted from the well-known study by Pacala and Socolow, who demonstrated that global emissions could be reduced to levels that would stabilize climate change with existing technologies.²⁶ They took the total amount of emissions reductions needed to stabilize emissions and split that amount into equal parts or wedges, with each wedge representing a certain amount of emissions reductions. The project team followed a similar approach.



The project team developed three wedges to reduce emissions from the off-road equipment and vehicle category to 1990 levels. The wedges are: the Low Carbon Fuel Standard (LCFS), a 35% fuel use reduction by pleasure craft, and a 15% improvement in fuel economy. Table 10 lists each wedge and the reduction in emissions it would achieve by 2020. The combined reductions represented by these three wedges is 0.7 MMT CO₂E by 2020 -- enough to slightly exceed the AB 32 emissions reduction target.

Table 10. Emissions Reduction Strategies for Off-Road Equipment and Vehicles Category

Emissions Reduction Wedge	Emissions Reduction (MMT CO₂E)	% of Total Reduction
Low-Carbon Fuel Standard	0.2	24%
35% Reduction of Pleasure Craft Fuel Consumption	0.1	13%
15% Improvement in Fuel Economy	0.4	63%
Total	0.7	100%

4.2.1. Low Carbon Fuel Standard (LCFS)

The Low Carbon Fuel Standard (LCFS) is expected to reduce greenhouse gas emissions by reducing the carbon content of fuel. It is primarily intended for on-road motor vehicles, but it is assumed that the same fuel will also be used by off-road equipment and vehicles, particularly gasoline and diesel fuel. As of this writing, CO₂E reductions due to the LCFS are not clearly defined or detailed; therefore, we assumed, as for the on-road transportation category in this study, that there will be a 10% CO₂E MMT reduction by 2020 due to the LCFS. For purposes of calculating the reduction potential of the LCFS in this category, we also assumed that it would be implemented and active by 2010.

4.2.2. 35% Fuel Use Reduction in Pleasure Craft (Boats)

Off-road pleasure craft in San Diego County are primarily boats. Since these boats are primarily dedicated to leisure and personal use and not an essential mode of transportation, it is speculated that an increase in fuel prices would deter people from using their boats as often or traveling as far. Taking into consideration the potential of increasing fuel prices, we assumed a 35% reduction in pleasure craft use and fuel consumption by 2020.

4.2.3. 15% Improvement in Fuel Economy

It is expected that on-road transportation fuel economy improvements driven by the Federal CAFE Standard will translate or be transferred via new technology to the pleasure craft industry. The on-road transportation category in some cases will realize a 50% improvement in fuel economy; therefore, it seemed reasonable to assume that this could translate into a 15% fuel economy improvement in the off-road equipment and vehicle category owing to technology transfer.

4.3. Methodology

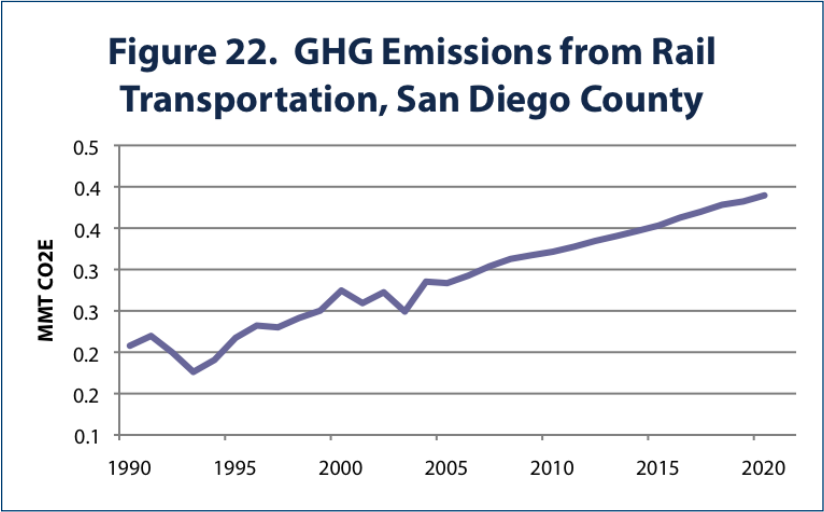
The GHG emissions inventory for this category includes the analysis of CO₂, CH₄, and N₂O. The data for this category were generated with the California Air Resource Board (CARB) emissions modeling tool OFFROAD. The computations from this model are based on three main factors: equipment and vehicle population, activity, and emissions factors. These factors account for variables such as equipment and vehicle type, technology, age, and horsepower as well as the type of fuel consumed. Seasonal operating conditions and adjustments for ambient temperature are also included in the computation.²⁷

5. Greenhouse Gas Emissions from Rail Emissions

The CARB inventory for the state of California includes emissions from rail as part of the transportation category. To be consistent, we have included information about the Rail category in this report on the “other transportation” categories.

5.1. Historical and Projected Emissions

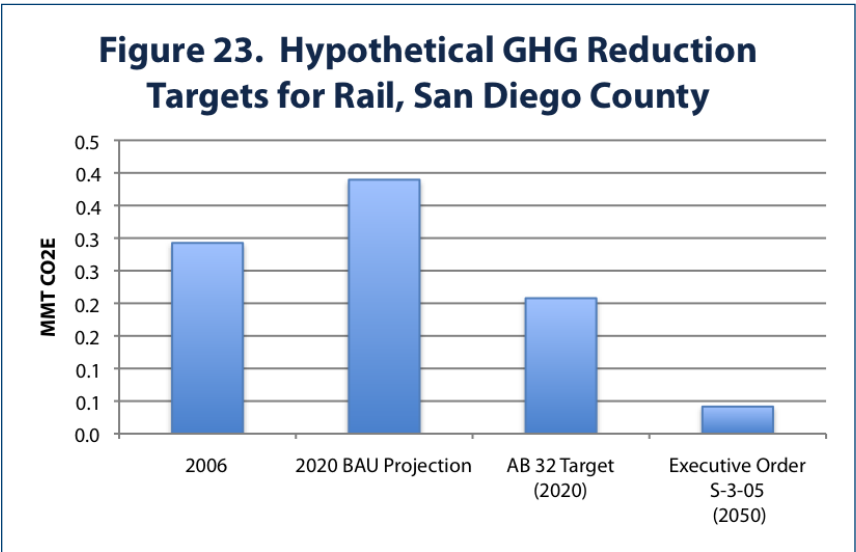
In 2006, emissions caused by the combustion of distillate fuels for use in rail transportation were 293,000 MT CO₂E, approximately 41% greater than the 1990 level of 208,000 MT CO₂E. The BAU projected level is estimated as 330,000 metric tons, 13% greater than the 2006 levels. Figure 21 shows the generally increasing trend in rail emissions over the 1990-2020 period. This trend is a linear projection from previous years. Transportation fuel costs is a significant factor in determining future emissions from the rail category. If high fuel prices cause a shift away from on-road transportation options, emissions from the rail category could increase, though overall emissions would be reduced due to the efficient nature (fuel use per person) of rail.



5.2. Emissions Reductions Targets

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide emissions to 1990 levels by the year 2020. Even though it does not specify reduction targets for specific areas or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied proportionally to San Diego County. To meet the targets established by AB 32, San Diego would have to reduce its projected business-as-usual 2020 annual emissions in this category by 0.2 MMT CO₂E or 47%.

Earlier, in 2005, Governor Schwarzenegger signed Executive Order S-3-05, which established long-term emissions reduction



targets of 80% below 1990 levels by 2050. While this target is not law, it is generally accepted as the ideal toward which California regulations are aiming. Like AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, emissions from rail transportation would have to be 0.04 MMT CO₂E per year – a reduction of 0.35 MMT CO₂E (89%) below the 2020 business-as-usual forecast. Figure 23 illustrates a comparison of GHG emissions reduction targets for AB 32 and Executive Order S-3-05.

Rail transportation is not the target of GHG emissions reduction strategies at this time. Rail is already a fuel-efficient method of transportation on a per capita as well as on a per unit of freight weight basis. Further, if rail use increases, it is possible that emissions from this category could increase while overall emissions could decrease due to the efficiency of rail. The project team did not calculate emissions reduction strategies for this category.

5.3. Methodology

Activity data for rail transportation were not available within the time-frame of this project; therefore, GHG emissions for the County were scaled from the CARB GHG inventory using US Economic Census data. For this, the project team used data on the “total sales, shipments, receipts, revenue or business done by domestic establishments” for rail transportation.²⁸

End Notes

1. Nilmini Silva-Send is the author of the Civil Aviation and Water-Borne Category reports.
2. Sean Tanaka is the author of the Off-Road Equipment and Vehicle Category report.
3. These regulations have been adopted by the Board and come into effect on different dates depending on the type of cold shoring method to be used, the earliest date of coming into effect for California is 2012, for the Port of San Diego the date is 2014. The Port is striving to provide cold ironing for its cruise ship terminal by January 2011, 3 years prior to the regulatory requirement. Approximately 50 ships per year are expected to use cold ironing before the required date. See <http://www.arb.ca.gov/regact/2007/shorepwr07/shorepwr07.htm>. The ARB rule on auxiliary diesel engines, adopted in 2005 and effective from January 2007 was struck down by the 9th Circuit upholding an August 2007 decision of a District Court, which found that the ARB regulation is preempted by the Clean Air Act (CAA), and that it wrongly complicates international commerce. Under the court ruling, the ARB must seek an EPA waiver for its marine engine regulation(s). While ARB pursues the waiver, it is also developing another rule, which would require ships to switch to low-sulfur fuels in their main engines when within 24 miles from California coasts, see <http://www.arb.ca.gov/ports/marinevess/marinevess.htm>.
4. Aviation gasoline is a high octane gasoline used for aircraft and racing cars. Jet fuel is unleaded kerosene with Jet-A being the US standard only used in the US.
5. A detailed explanation of the two methods is provided in Section 1.3.
6. Concern has led to a petition by Friends of the Earth to the EPA to regulate or evaluate the environmental and health effects of leaded aviation gasoline, see http://www.avweb.com/avwebflash/news/GroupAsksEPAToGetTheLeadOutOfAvgas_196596-1.html.
7. The future availability of aviation gasoline has led companies to develop alternatives. See “Teledyne Continental Plans Certified Diesel within two years”, February 2008, at <http://www.avweb.com/eletter/archives/avflash/1054-full.html>.
8. California Energy Demand 2008-2018 Staff Revised Forecast. California Energy Commission (CEC) November 2007.
9. Airport Master Plan, San Diego International Airport, October 2007, available at http://www.san.org/airport_authority/airport_master_plan/index.asp
10. The number of enplanements is not the same as the number of passengers. Enplanements refer to the actual number of passengers boarding aircrafts, whereas the number of passengers is roughly double the number of enplanements and assumed to be in an airport at any one time. The number of passengers is the value used for airport expansion plans.
11. Forecasts for 2010, 2015, and 2020 are from the San Diego County Regional Airport’s Master Plan, 2005 with interpolated values between.
12. Daggett, D.L, Hendricks, R.C., Walther, R. and Corporan, E., Alternate Fuels for use in Commercial Aircraft. This research is being carried out by a consortium consisting of Boeing, NASA Glenn Research Center, MTU Aero Engines (Germany) and the US Air Force Research Laboratory. Some of the algal based biofuels research is being carried out at UCSD, San Diego. Available on-line at: http://www.boeing.com/commercial/environment/pdf/alt_fuels.pdf
13. <http://www.arb.ca.gov/cc/inventory/data/data.htm>.

14. Global warming potentials of 21 and 310 for methane and nitrous oxide were used by CARB and are from the UNFCCC IPCC report of 1995, http://unfccc.int/ghg_data/items/3825.php. The more recent revised IPCC GWP values were not used in order to be consistent with all the remaining county-wide inventory category reports as well as the CARB existing state-wide inventory.
15. <http://www.transtats.bts.gov/>. The departure miles for 1990 are not available and were backcast from the 1991-2007 linear plot.
16. A preliminary analysis for just one year, 1991, of the aircraft type mix in San Diego versus the aircraft type mix in California showed that San Diego had a more modern and therefore more fuel efficient fleet than the state. Time did not permit further evaluation to establish if this were true for all years to 2006. If it does hold true to the present day, then the emissions caused by the aircraft fleet in San Diego will be somewhat lower than the average of California.
17. The project team submitted a detailed data request to the APCD for all fuel used in San Diego County. This included emissions from aviation activities.
18. Hotelling is an alternative term used for ships at berth, usually at port.
19. This is the value provided by CARB in "Emissions Estimation Methodology for Ocean-Going Vessels", May 2008, Table ES-2 together with the harbor craft emissions value available in the San Diego Port Emissions Inventory of 2007. A greenhouse gas emissions inventory for the Port was carried out as part of an air emissions inventory by Starcrest Consultants for 2006, see <http://www.portofsandiego.org/environment/clean-air/65-clean-air/581-clean-air-program-overview.html>. The total carbon dioxide equivalent emissions for OGVs and harbor craft from this study were 83,773 metric tons in 2006. Although the basic methodology used by CARB and Starcrest is the same (see Section 3, Methodology), differences are attributed to mainly to the inclusion of OGVs that pass through County waters, and less due to differences in vessel speed and engine load factors. In addition, the Starcrest fuel consumption data may differ from CARB fuel consumption data. The emissions factors for greenhouse gases used by CARB and Starcrest are the same.
20. See End Note 1.
21. Table 5 through Table 8 form part of the methodology used by CARB and were provided by CARB in "Emissions Estimation Methodology for Ocean-Going vessels", May 2008.
22. CARB describes its allocation of harbor craft to the ports. The vessels with home ports far away from navigable waters were assigned to the nearest port. Those that did not have a home port were assigned the port of the owner or operator. Those that had a home port outside California were assigned the port at which they landed their catch. See Appendix B, Emissions Estimation Methodology for Commercial Harbor Craft operating in California, 2007, provided by CARB and available at <http://www.arb.ca.gov/regact/2007/chc07/appb.pdf>.
23. See Port of San Diego 2006 Emissions Inventory, 2007 at <http://www.portofsandiego.org/environment/clean-air.html>.
24. The cruise ship growth data was taken from the Marketing Department forecast provided by the Port and all other growth forecasts provided by the Port are from the San Diego Unified Port District Maritime Business Plan (April 2007), pages 4-27 to 4-29 available at: <http://www.portofsandiego.org/maritime/593-port-challenges-initiative-to-redevelop-the-tenth-avenue-marine-terminal-.html>
25. Most of the pleasure craft in San Diego County are boats or other type of water vehicle. Recreational vehicles are in a different category.
26. S. Pacala and R. Socolow: Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies, Science, 13 August 2004, vol. 305, pp. 968-972.
27. California Air Resources Board, "Overview: OFFROAD Model" last viewed May 25, 2008, at http://www.arb.ca.gov/msei/offroad/pubs/offroad_overview.pdf
28. The economic data for the state of California is available at: http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=04000US06&-ds_name=EC0200A1&-_lang=en. The equivalent data for the County of San Diego is available at: http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=31000US41740&-ds_name=EC0200A1&-_lang=en



San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

Industrial Processes and Products Report

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Industrial Processes and Products Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

Industrial activities generate greenhouse gas emissions in a variety of ways, such as from the use of electricity and natural gas energy supplies to provide power and heat (indirect emissions). Industrial emissions also result from the processing of materials to manufacture items including mineral aggregate products, chemicals, metals, refrigerants, electronics and other consumer goods such as paper and food items. Furthermore, high global warming potential gases are used in air conditioning and refrigeration systems, and during the manufacture of electronics, fire protection equipment, insulation, and aerosols. This report, a component of the San Diego County Greenhouse Gas Inventory project, focuses on industrial processes that directly release carbon dioxide and other greenhouse gases by processes other than fuel combustion, and on the use of industrial products, mainly refrigerants, by all sectors – in vehicles, in homes, and in commercial and industrial facilities. These sources are currently responsible for about 5% of the total greenhouse gas emissions in San Diego County. Greenhouse gas emissions associated with fuel combustion activities of industrial processes are captured in other sections of the inventory.

This report provides an estimate of historical GHG emissions associated with industrial processes and products from 1990 to 2006 and projects future emissions to 2020 for San Diego County. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for the region's industrial sector. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to reduce emissions to 1990 levels by 2020 – the statewide statutory target under AB 32. Finally, the report identifies and quantifies potential emissions reduction strategies to determine the feasibility of reducing industrial emissions to 1990 levels by 2020.

To the extent possible, the project team followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide GHG inventory. In some instances, when county-specific data was not available, the project modified the CARB method.

This report, which is intended as an overview of the findings from research and analysis conducted for the industrial processes and products category, includes the following sections.

- Section 2 provides an overview of industrial GHG emissions in San Diego County, including total emissions, a breakdown of emissions by subcategory, a summary of the highest emitting products and activities, projections to 2020, and reduction targets.
- Section 3 discusses the strategies necessary to reduce industrial emissions to 1990 levels by 2020.
- Section 4 provides a detailed discussion of the method used to estimate emissions for this category.

1.1. Key Findings

The key findings of the report are summarized below.

- In 2006, GHG emissions from industrial processes and products (defined above) totaled 1.6 million metric tons of carbon dioxide equivalent (MMT CO₂E), about 5% of San Diego County's overall emissions.

- 80% of the current emissions in the category are from the use of HFC refrigerants, which are replacing banned CFCs and soon-to-be-phased-out HCFCs. (CFCs and HCFCs are not included in GHG inventories.)
- Because HFCs were not in wide use in 1990, emissions in this category have more than tripled since 1990.

2. Greenhouse Gas Emissions From Industrial Processes and Products

Emissions from industrial processes and products totaled 1.6 MMT CO₂E in 2006, about 5% of the total emissions from San Diego County, as shown in Figure 1. In 1990, emissions in the category totaled only 0.5 MMT CO₂E, or about 1.6% of total county emissions. Eighty percent of current greenhouse gas emissions in this category (in CO₂E) are due to hydrofluorocarbon (HFC) refrigerant gases that have replaced banned chlorofluorocarbons (CFCs), and are replacing hydrochlorofluorocarbons (HCFCs), which are being phased out as part of the Montreal Protocol on the Protection of the Ozone Layer. (Although they are significant greenhouse gases, neither CFCs nor HCFCs are included in GHG inventories because their use has already been restricted.) The rapid increase in HFC use in San Diego County since 1990 accounts for the large increase in emissions from this category.

Major 2006 emissions in this category are shown in Figure 2. HFC emissions, especially HFC 134a from automobile air conditioners, constitute the largest source of industrial GHG emissions in the County. While HFCs do not harm the ozone layer, the C-F bonds they contain powerfully absorb infrared radiation and thus are significant greenhouse gases (see Table 1 for global warming

Figure 1. San Diego County GHG Emissions by Category (2006)

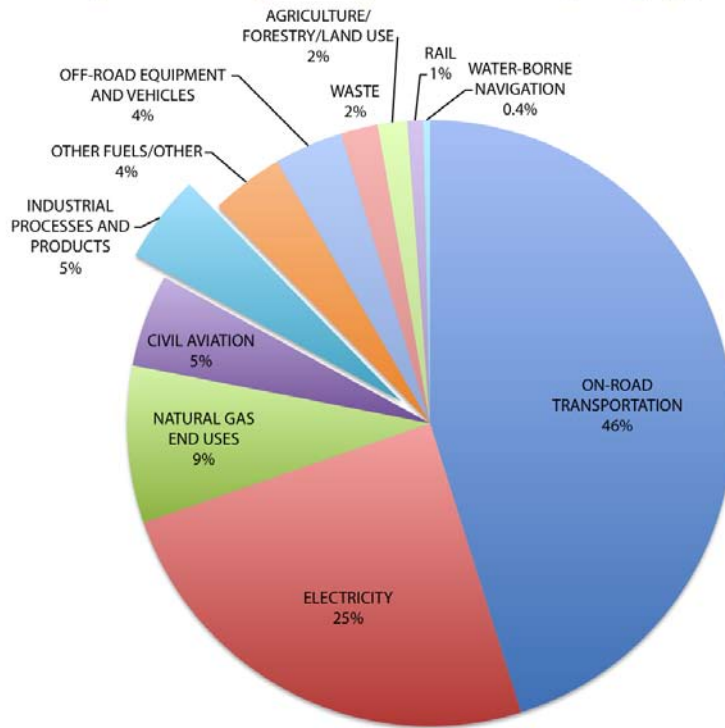
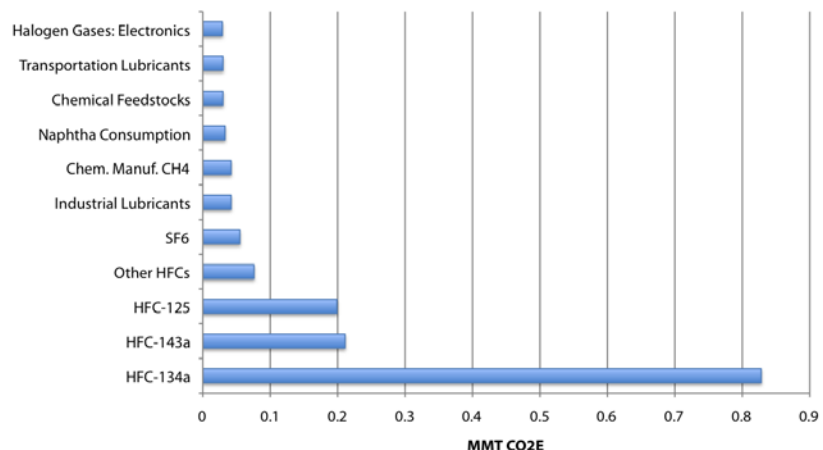


Figure 2. Top 11 GHG Sources, Industrial Process/Products San Diego County 2006



potential (GWP) data).¹ HFCs are used in automobile, home and commercial air conditioning, home and commercial refrigeration, and industrial process refrigeration.

After HFC refrigerant gases, the next largest contributor to global warming in this category is sulfur hexafluoride (SF₆). The release of this compound is associated with gas-insulated switch gear used in electricity transmission. Because of an extremely long atmospheric lifetime and high GWP, the release of even a small amount of SF₆ is significant, and these releases constituted 3.4% of the total carbon dioxide equivalent emissions in this category in San Diego County. High-GWP halogenated gases are also released during the manufacture of electronics. This source is responsible for 2.3% of the county total in this category. Carbon dioxide emissions were smaller contributors to this category: industrial lubricant consumption (2.6%), natural gas consumption by chemical manufacturers (2.6%), industrial naphtha consumption (2.0%), and petroleum feedstock consumption by chemical manufacturers (2.0%). All other sources were less than 2% of the category total as of 2006.

Table 1. Global Warming Potential of Industrial Gases

Greenhouse Gas	Global Warming Potential (GWP, 100-year)
CO ₂	1
CH ₄	21
HFC-134a	1300
HFC-125	2800
HFC-143a	3800
SF ₆	23,900

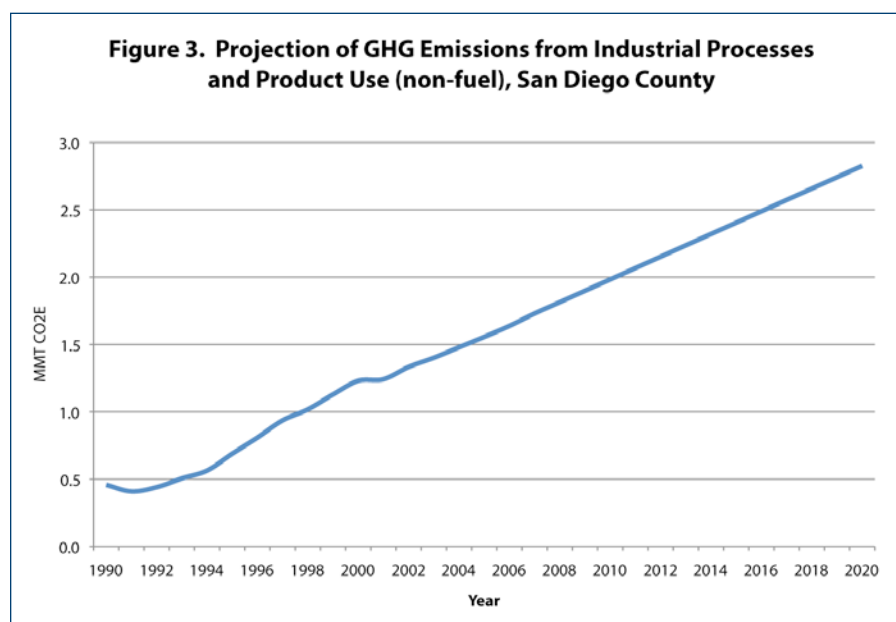
2.1. Emissions Projections and Reduction Targets

Because HFCs were not in use in 1990, emissions in the industrial processes and products category have already tripled. Figure 3 shows a linear trend extrapolated beyond 2004. By 2020 under a business-as-usual scenario, we predict emissions of 3 MMT CO₂E – more than a six-fold increase over 1990 levels (0.5 MMT CO₂E).

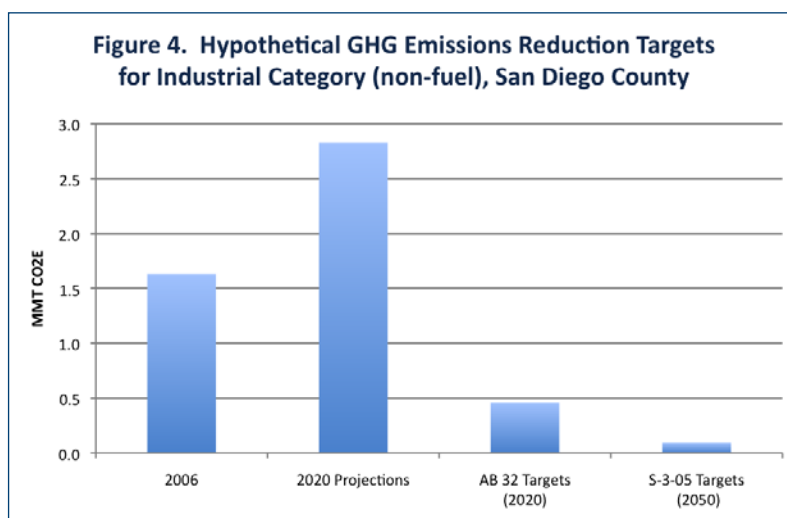
In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on GHG emissions in California.

AB 32 seeks to reduce statewide GHG emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County. To meet the targets established by AB 32 (1990 levels by 2020) the San Diego region would have to reduce its 2020 emissions from industrial processes and products by 2.4 MMT CO₂E – an 84% reduction.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for GHG emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied



hypothetically to San Diego County, total emissions from industrial processes and products would have to be reduced to 0.09 MMT CO₂E –a reduction of 2.7 MMT CO₂E (97%) below the 2020 business-as-usual projection. Figure 4 shows projected 2020 and actual 2006 emissions levels compared to the AB 32 and Executive Order S-3-05 targets.



3. Emissions Reduction Strategies

To reach emissions reductions targets set by AB 32, the industrial processes and products category will have to reduce emissions by approximately 2.4 MMT CO₂E below the business as usual projection for 2020. To illustrate how the region could achieve the AB 32 targets and reduce emissions by this amount, the project team identified strategies and calculated the potential emissions reductions for each. The results were used to develop reduction “wedges,” illustrated in Figure 4. This approach was adapted from the well-known study by Pacala and Socolow, demonstrating that global emissions could be reduced to

levels that would stabilize climate change with existing technologies.² They took the total reductions needed to stabilize emissions and split that amount into equal parts or wedges, each wedge representing a certain amount of emissions reduction. The project team followed a similar approach to show how the San Diego region might reduce its GHG emissions to meet AB 32 targets.

To develop an emissions reduction wedge for non-fuel industrial emissions, the project team used statewide reduction strategies developed by CARB. In its Climate Change Draft Scoping Plan of June 2008, CARB identified preliminary strategies to reduce emissions from high global warming potential gases (Table 2).³ These comprehensive measures are expected to result in a 16 MMT CO₂E statewide reduction in emissions by 2020.

Table 2. Emissions Reduction Measures for High GWP Gases in CARB Draft Scoping Plan

Motor Vehicle Air Conditioning Systems: Reduction of Refrigerant Emissions from Non-Professional Servicing (Discrete Early Action)

SF6 Limits in Non-Utility and Non-Semiconductor Applications (Discrete Early Action)

High GWP Reduction in Semiconductor Manufacturing (Discrete Early Action)

Limit High GWP Use in Consumer Products (Discrete Early Action)

High GWP Reductions from Mobile Sources

- Low GWP Refrigerants for New Motor Vehicle Air Conditioning Systems
- Air Conditioner Refrigerant Leak Test During Vehicle Smog Check
- Refrigerant Recovery from Decommissioned Refrigerated Shipping Containers
- Enforcement of Federal Ban on Refrigerant Release during Servicing or Dismantling of Motor Vehicle Air Conditioning Systems

High GWP Reductions from Stationary Sources

- High GWP Recycling and Deposit Program
- Specifications for Commercial and Industrial Refrigeration
- Foam Recovery and Destruction Program
- SF6 Leak Reduction and Recycling in Electrical Applications
- Alternative Suppressants in Fire Protection Systems
- Residential Refrigeration Early Retirement Program

If scaled down to San Diego County using ratios of industrial activity, these measures would reduce GHG emissions by 1 MMT CO₂E by 2020 (Figure 5).

While it is clear that overall reduction targets of AB32 (1990 levels by 2020) will not be applied directly to individual sectors of the economy, we are using it as a benchmark within each sector to evaluate whether the sector may be able to contribute meaningful reductions at the regional level.

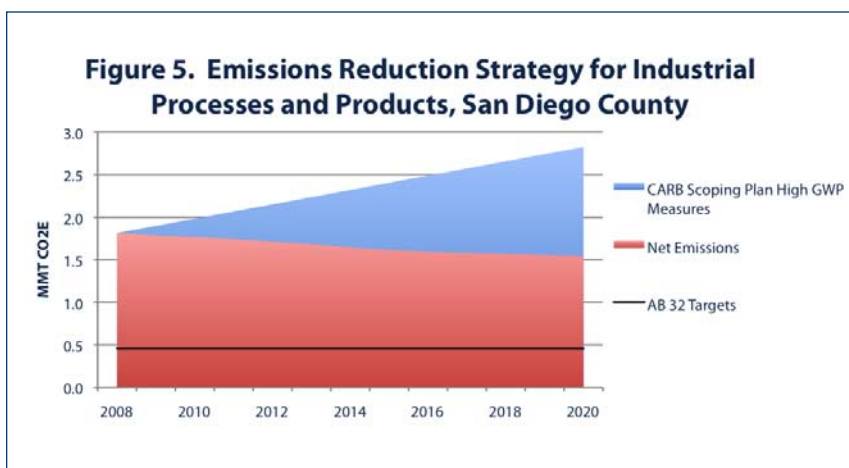
Savings expected from the HFC reductions included in the CARB Scoping Plan would not achieve the reductions necessary for the industrial processes and product use category to reduce its emissions to 1990 levels by 2020; however, the AB 32 goal could be fully accomplished within the category by phasing out HFC refrigerants in favor of low-GWP alternatives such as hydrocarbon refrigerants, which are currently legal in the U.S. only in industrial process refrigeration due to flammability concerns. Several alternatives to HFCs have already been commercialized, however. If HFCs are not phased out, reductions in other sectors would be required to compensate for reduced but continued HFC use in 2020.

To reach the goals included in Executive Order S-3-05 – 80% below 1990 by 2050 – within this category, HFC refrigerants will need to be phased out in favor of systems using gases that have negligible GWPs. In addition, further reductions in all of the other top 11 categories (e.g. SF₆ emissions from electricity generation and halogenated gas emissions from electronics manufacturing) would be required. The replacement of SF₆ with other insulators is considered technically feasible, and would result in a 90% reduction in SF₆ released to the atmosphere.⁴

4. Methodology

In general, the project team used the categories contained the CARB Greenhouse Gas Emissions Inventory and either calculated emission directly from primary data or scaled down statewide emissions based on a ratio of industrial activity in San Diego County and the state as a whole. Emissions from the following IPCC categories as used in the CARB GHG inventory were set to zero because Economic Census data from 1997 and 2002 from the US Census Bureau indicated no economic activity in San Diego County:

- 2A1: Manufacturing : Stone, Clay, Glass & Cement : Cement > Clinker production > CO₂
- 2A2: Manufacturing : Stone, Clay, Glass & Cement : Lime > Lime production > CO₂
- 2B2: Manufacturing : Chemicals & Allied Products : Nitric Acid > Nitric acid production > N₂O
- 2H3: Petroleum Refining : Transformation > Fuel consumption



Emissions from the following categories were set to zero because the California state greenhouse gas inventory (CARB, 2007) indicated no emissions statewide over the period 1990 – 2004:

- 2D2 Paraffin wax use: Not Specified Industrial > Fuel consumption - Waxes > CO₂
- 2D4: Not Specified Industrial > Fuel consumption - Asphalt > CO₂

Emissions from the following categories were calculated using the same methods as in the California state greenhouse gas inventory (CARB, 2007):

- 2E: Manufacturing : Electric & Electronic Equip. : Semiconductors & Related Products > Semiconductor manufacture > Halogenated gases (in CO₂E.). These emissions were taken from the EPA's national inventory, May 2008 version (<http://www.epa.gov/climatechange/emissions/usinventoryreport.html>) and ratioed to the value of semiconductor shipments. Semiconductor shipment data is available by county for 1997 and 2002 in economic census data from the US Census Bureau. Ratios were assumed constant before 1997 and after 2002 and extrapolated linearly between 1997 and 2002.
- 2F: Not Specified Not Specified > Use of substitutes for ozone depleting substances > CF₄, HFC-125, HFC-134a, HFC-143a, HFC-23, HFC-236fa, HFC-32, and other ODS substitutes. These emissions were taken from the most recent California state inventory (CARB, November 2007) and ratioed to population. State emissions for 2005 and 2006 were estimated using a linear fit to 1996 – 2004 data. Annual population data is from the US Census Bureau.
- 2G4: Not Specified Industrial > Soda ash consumption > CO₂. These emissions were taken from estimates of national soda ash consumption (<http://minerals.usgs.gov/ds/2005/140/sodaash.pdf>, 1990 - 2004), ratioed to population (annual data from the US Census Bureau), and multiplied by a MMT-soda-ash-to-MMT-CO₂ conversion factor of 0.415. National soda ash consumption in 2005 and 2006 was estimated using a linear fit to 1996 – 2004 data.

Emissions from the following categories were not performed using the same methods as the California state inventory (CARB 2007) because data on industrial production and consumption of resources is not available at the county level with sufficient detail. Instead, emissions were estimated from California state emissions (CARB, 2007) using ratios of industrial (or vehicular) activity in San Diego County and California, as described below. In all cases, state emissions for 2005 and 2006 were estimated using a linear fit to 1996 – 2004 data. Economic data was taken from 1997 and 2002 economic census data (US Census Bureau), the only two years with county data available. Ratios of county-to-state manufacturing activity were assumed constant before 1997 and after 2002, and linearly interpolated between 1997 and 2002 since no other data was available.

- 2B: Manufacturing : Chemicals & Allied Products > Fuel consumption. These emissions were ratioed from the California state inventory (CARB, 2007) based on the total value of chemical manufacturing shipments.
- 2D1: Not Specified Industrial > Fuel consumption - Lubricants > CO₂
- 2D4: Not Specified Industrial > Fuel consumption - Naphtha > CO₂
- 2D4: Not Specified Industrial > Fuel consumption - Other Petroleum Products > CO₂

- 2G4: Not Specified Industrial > CO₂ Consumption > CO₂
- 2G4: Not Specified Industrial > Limestone and dolomite consumption > CO₂. The emissions from these categories were ratioed from the California state inventory (CARB, 2007) based on the total value of all manufacturing shipments.
- 2D1: Not Specified Transportation > Fuel consumption - Lubricants > CO₂. These emissions were ratioed from the California state inventory (CARB, 2007) based on the total annual vehicle miles traveled in 1990, 1995, 2000, 2005, and 2006 as estimated by the California Department of Transportation (<http://www.dot.ca.gov/hq/tsip/smb/documents/mvstaff/mvstaff60.pdf>). Ratios in intervening years were linearly extrapolated.
- 2G1b - Use of Electrical Equipment: Imported Electricity : Not Specified > SF₆ use > SF₆
- 2G1b - Use of Electrical Equipment: In-State Generation: Not Specified > SF₆ use > SF₆. These emissions were ratioed from the California state inventory (CARB, 2007) based on the total electricity generated by and imported to the state and county (http://www.sdreo.org/uploads/Regional_Energy_Strategy_Final_07_16_03.pdf (1990 - 2002, p15), http://www.energy.ca.gov/electricity/electricity_by_county_2005.html, linear extrapolation for 2003 and 2004.). The percentage of county electricity consumed that is imported from outside the county is estimated in this work (see electricity report).

The potential reduction wedges provided in section 3 were calculated based on measures either approved or being discussed now at the state level. The Discrete Early Action Measure already approved for adoption under AB 32 targets only HFC 134a and is expected to lead to a reduction of an average 1 MMT CO₂E statewide. This reduction is a part of the total expected statewide 16 MMT to be achieved through the proposed measures to reduce emissions of all high Global Warming Potential gases (see End Note 2). This reduction was converted to a county level by multiplying by the projected population ratio of San Diego County to California in 2020.

4.1. Limitations

This analysis could be improved by the addition of data on the industrial consumption of the following raw materials at the county level.

Consumption by manufacturers of chemicals and allied products of:

- Liquefied petroleum gas (LPG)
- Natural gas
- Petroleum feedstocks
- Consumption by lubricants in transportation.

Industrial consumption of:

- Lubricants
- Naphtha
- Other petroleum products
- Carbon dioxide
- Limestone and dolomite

End Notes

1. Data from the United Nations Framework Convention on Climate Change, 1995, accessed at http://unfccc.int/ghg_data/items/3825.php on May 15, 2008.
2. S. Pacala and R. Socolow, Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science, 13 August 2004, Vol 305, pp. 968-972.
3. These potential measures are described in the Draft AB32 Scoping Plan Document is available at <http://www.arb.ca.gov/cc/scopingplan/document/draftscopingplan.htm>, page 26.
4. Maiss, M. and Brenninkmeijer, C. A. M. Atmospheric SF₆: Trends, Sources, and Prospects. Environ. Sci. Technol. 32 (20) 3077-3086 (1998)



San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and Strategies to Achieve AB 32 Targets

Waste Report

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September 2008





Waste Report

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1. Introduction

Emissions from landfills and wastewater treatment constitute about 2% of greenhouse gas emissions (GHG) in the County. Biodegradable, carbon-bearing wastes decompose under largely anaerobic conditions to produce landfill gas composed of approximately 50% methane and 50% carbon dioxide. Methane is a more powerful greenhouse gas by a factor of 21¹ than carbon dioxide and degradable wastes in landfills continue to degrade for several decades. The treatment of domestic wastewater also results in the release of methane as well as nitrous oxides.

This report, a component of the San Diego County Greenhouse Gas Inventory project, provides an estimate of historical GHG emissions associated with both components of the waste category from 1990 to 2006 and projected future emissions to 2020 for the region. Emissions associated with waste disposal and wastewater treatment, such as transportation activities, are captured in other sectors of this inventory. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, this report also establishes emissions reductions targets for this sector. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the project team calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) to achieve the AB32 statutory target of 1990 levels by 2020. Finally, the report identifies and quantifies potential emissions reduction strategies to evaluate the feasibility of reducing waste-related emissions to 1990 levels by 2020.

To the extent possible, the project team followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide GHG inventory. In some instances, when doing so could yield a more accurate or precise result, the project modified the CARB method. This report includes the following sections.

- Section 2 provides an overview of GHG emissions for the waste category total emissions divided into its two components, landfill emissions and wastewater treatment emissions from 1990 to 2020;
- Section 3 discusses the potential strategies to reduce landfill gas emissions beyond 2020 levels;
- Section 4 provides the method used to estimate emissions for this category.

1.1. Key Findings

The key findings are as follows:

- In 2006, GHG emissions from the waste category totaled 0.7 million metric tons of carbon dioxide equivalent (MMT CO₂E), about 2% of San Diego County's overall emissions.
- Both biogas and landfill gas have been captured for combustion and electricity production since at least 1997; therefore, the current (2006) total emissions of approximately 0.7 MMT are nearly 30% lower than the total emissions in 1990, which was modeled to have been 0.9 MMT.
- Landfill emissions constitute the larger of the two sources of waste sector emissions today. Carbon-bearing wastes still constitute more than 55% of the total waste disposed.
- Waste disposal per capita at landfills has increased from 1.2 metric tons in 1990 to 1.4 metric tons in 2005, despite the requirement for 50% diversion of waste disposed established in 1989 by the state of California. In 2005, San Diego County reported 48% diversion of total waste disposed.

- At the current rate of emissions growth and emissions controls, assuming no changes in percentage capture of landfill gas and biogas, and no changes in the per capita waste disposed, the business-as-usual (BAU) level is projected to be 0.9 MMT in 2020. Therefore, the 1990 baseline will not be exceeded until after 2020.
- The Discrete Early Action Measure currently approved by CARB under AB32 to increase landfill gas capture can provide an additional reduction of 0.3 MMT by 2020.
- The Executive Order S-3-05 target of 80% below 1990 levels means reaching total waste sector emissions of 0.2 MMT by 2050.
- The key limitation in the estimation of landfill emissions is the lack of accurate data for waste disposed at the 26 landfills in the County, and the need to interpolate and backcast the amount and composition of waste disposed. Based on the waste-disposed data available for one major landfill in the county (Miramar), it appears that landfill emissions may be underestimated. More data will be needed to more accurately assess emissions. On the other hand, the second limitation is the lack of landfill and biogas capture data for 1990. This may result in overestimation of the methane emissions for 1990.

2. GHG Emissions from Waste Sector

The following components are included in the waste sector of this inventory, consistent with the categories used in the CARB statewide Greenhouse Gas Inventory²:

- Landfill emissions
- Emissions from domestic wastewater treatment and discharge
- Emissions from industrial wastewater treatment and discharge

Industrial wastewater consists of manufacturing and agricultural process wastewater. However, San Diego County has insignificant manufacturing and agricultural wastewater discharge and treatment. Any manufacturing or agricultural wastewater is reported to be pre-treated and discharged to the domestic wastewater system.³ Therefore, this component is not included in the inventory as a separate item.

2.1. Landfills

Biodegradable, carbon-bearing wastes decompose under largely anaerobic conditions to produce landfill gas composed of approximately 50% methane and 50% carbon dioxide. Degradation is caused by bacteria which make use of the water content in the waste to cause degradation. Without water, no degradation will take place. Thus, a large fraction of carbon-bearing wastes will actually be sequestered as long as anaerobic conditions prevail and as long as the moisture content is low. The degree of compaction will also determine the availability of moisture for the degradation process. In addition, the moisture is often not uniformly distributed so that the degradation process is uneven through the landfill.⁴

Methane is a more powerful greenhouse gas by a factor of 21 than carbon dioxide and degradable wastes in landfills continue to degrade for several decades.⁵ As long as carbon-bearing wastes are disposed in the landfill and sufficient moisture exists, degradation can occur from periods of 5 to 50 years. The highly biodegradable waste such as garden and newspaper decomposes more quickly to produce gas in the early years and gas production will begin within the first year of deposition. Other carbon-bearing wastes such as lumber are slower to degrade and may continue to do so over decades. Therefore carbon bearing wastes

disposed today may still be degrading for decades after closure of the landfill although commercially viable amounts of methane may not be available for more than 20-30 years after closure.⁶

Most landfills are now equipped with landfill gas collection systems for the purposes of odor control by flaring and increasingly for the production of electricity. In either case, the methane emitted to the atmosphere – and net carbon dioxide equivalent emissions – will decrease. In addition, California's solid waste and recycling law AB 939 of 1989 mandated local jurisdictions, for the sake of limited disposal capacity, to meet numerical total waste diversion goals of 25% by 1995 and 50% by 2000.⁷

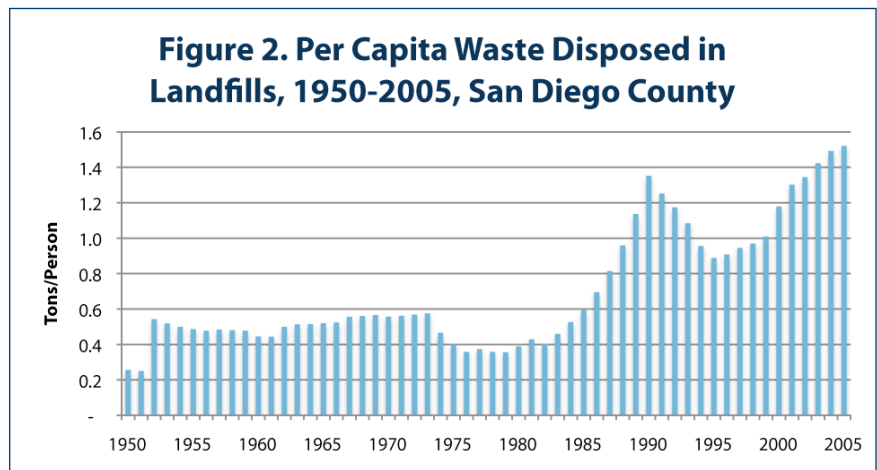
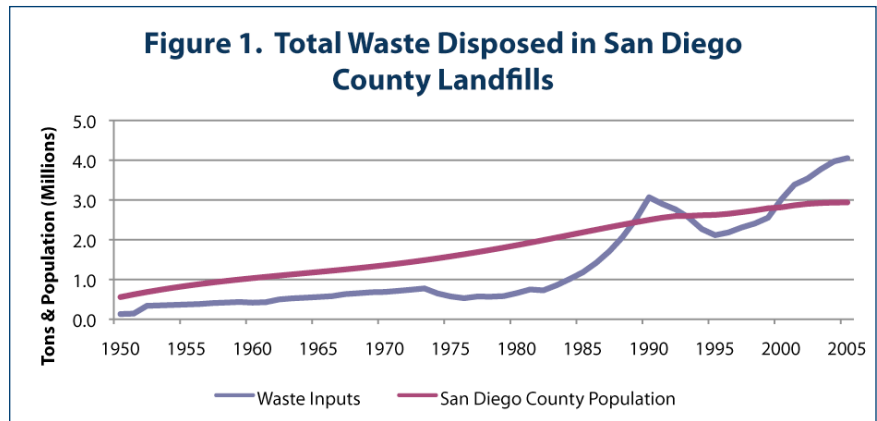
San Diego County reports its diversion rate at 48% in 2005.⁷ Despite this diversion, the waste disposed (Figure 1) has continued to increase after a large dip during the 1990s.⁹

The per capita waste disposed (Figure 2) has increased from 1,230 kilograms (1.2 metric tons) per year in 1990 to 1,380 kilograms (1.4 metric tons) in 2005.¹⁰ A diversion rate of 48% means that the waste generated per capita is even greater, since the per capita data here only represents waste disposed at landfills.

Minor amounts of non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of nitrous oxide (N_2O), nitrogen oxides (NO_x) and carbon monoxide (CO) are also produced from the degradation process. However, these are not significant relative to the methane and carbon dioxide emissions. For the whole of the state of California, the N_2O emissions in carbon dioxide equivalents are of the order of $10e-7$ MMT.¹¹ This component is therefore much less significant in San Diego County and is not included in the San Diego waste sector emissions.

Currently, 372 landfills have been identified by the California Integrated Waste Management Board (CIWMB) in the state of California as having received or still receiving carbon-bearing wastes, of which 26 are located in San Diego County. Eight landfills are active in San Diego County. Three are operated by the City of San Diego, and the remaining are under the jurisdiction of the County Public Works Department, the local enforcement agency for the CIWMB.¹²

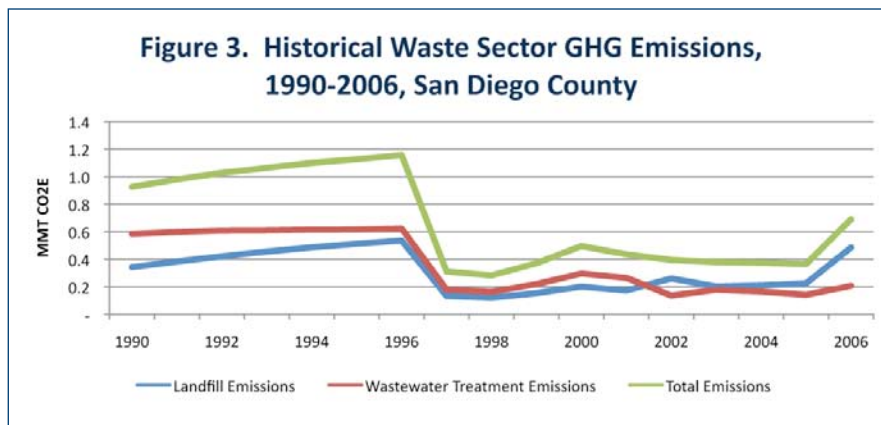
Landfill gas has been collected from 20 out of 26 landfills at least since 1997. CARB data indicates that a few landfills may have flared landfill gases from 1990.



2.2. Domestic Wastewater Treatment

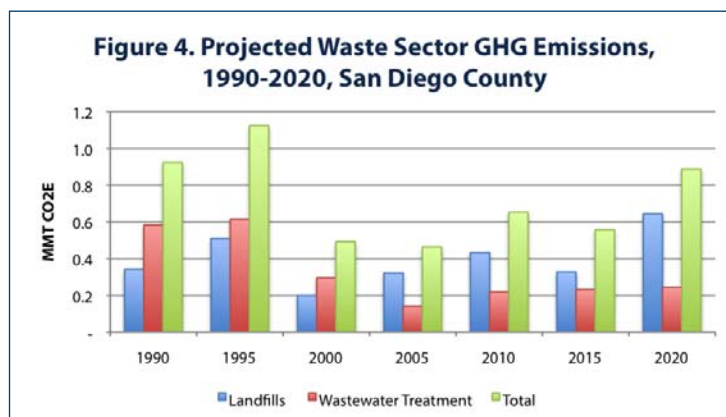
The city of San Diego operates three water treatment plants. The treatment of domestic wastewater produces sludge which is pumped into digesters where a bacterial digestion process is applied to produce methane gas. The Point Loma plant has 8 digesters to produce its own methane and electricity, and surplus electricity is fed into the grid. Excess sludge is piped to three digesters at the Metro Biosolids Center (MBC), located adjacent to the Miramar landfill. These digesters produce methane and heat used to run the digestion process while the methane, along with methane generated at the landfill, is burned to produce electricity. These cogeneration facilities produce about 10 MW of power, while the MBC digesters produce about 6.4 MW and the sludge from the North City plant is used to produce about 3.8 MW of which 75% is used for energy self sufficiency.

In 1990, the emissions from landfill gas and domestic wastewater treatment were 0.9 MMT CO₂E. In 2006, the level was 0.7 MMT CO₂E, a decrease of about 30%. The primary reason for this reduction is the diversion of landfill and wastewater treatment gases, recorded since 1997. Figure 3 shows waste sector emissions from 1990 to 2006.



2.3. Emissions Projections and Reduction Targets

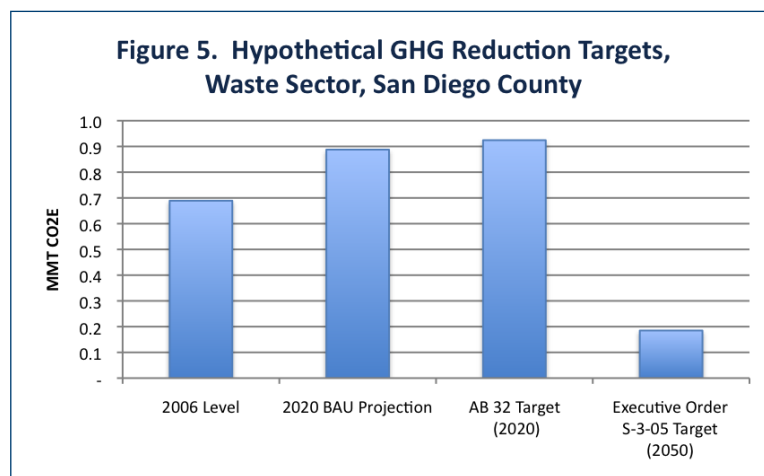
The BAU emissions projection for this category was made based on current levels of per capita waste disposal (1.38 metric tons per person), projected population growth, the average percentage of landfill gas capture over the period 1996-2006 (67%), and the average capture rate of biogas (71%). Forecasts of wastewater discharge emissions were based on population growth, since the emissions are based on a grams-per-person value (see Methodology section, below). With these assumptions, the GHG forecast for this sector in 2020 is expected to be approximately 0.9 MMT. The greenhouse gas forecasts for the waste sector from 2007 to 2020 are provided in Figure 4.



In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on GHG emissions in California. AB 32 seeks to reduce statewide GHG emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County. Due largely to the capture of landfill and biogas since at least 1997, the 1990 baseline is not projected to be exceeded until after 2020.

In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for GHG emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, the waste sector emissions would have to be approximately 0.18 MMT CO₂E. This would require an emissions reduction of approximately 0.5 MMT CO₂E (73%) from the 2006 level.

Figure 5 shows projected 2020 and actual 2006 emissions levels compared to the AB 32 and Executive Order S-3-05 targets.



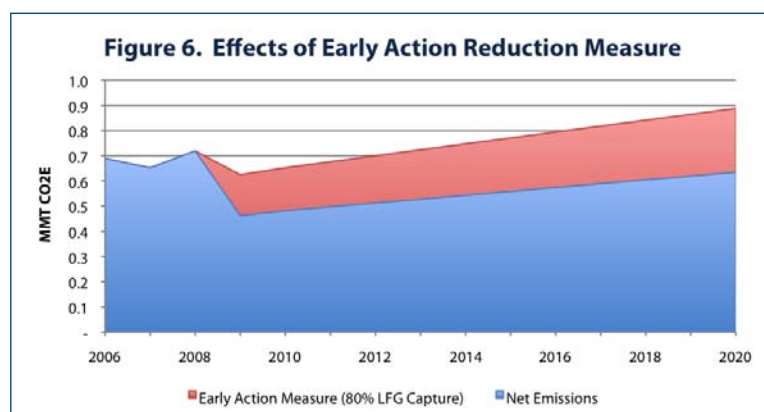
3. Reduction Strategies (Wedges)

Because both biogas and landfill gas have been captured for combustion and electricity production since at least 1997, the current (2006) total emissions of approximately 0.7 MMT are nearly 30% lower than the total emissions in 1990, which was modeled to have been 0.9 MMT. Provided the current rate of emissions growth does not change, there are no changes in percentage capture of landfill gas and biogas, and no changes in the per capita waste disposed, the business-as-usual (BAU) level is projected to be 0.9 MMT in 2020. Therefore, the 1990 baseline will not be exceeded until after 2020.

Nevertheless, further reductions in this sector may be able to contribute to a small extent to offset emissions in other sectors, and also contribute to achieving the target set by Executive Order S-03-05 for 2050. An Early Action Measure has been promulgated by CARB for increasing landfill gas capture in the state. An alternative more long-term strategy only for the purpose of reducing greenhouse gases may be provided by reducing the carbon-bearing material disposed in landfills to reduce and eventually halt the production of methane from landfills.

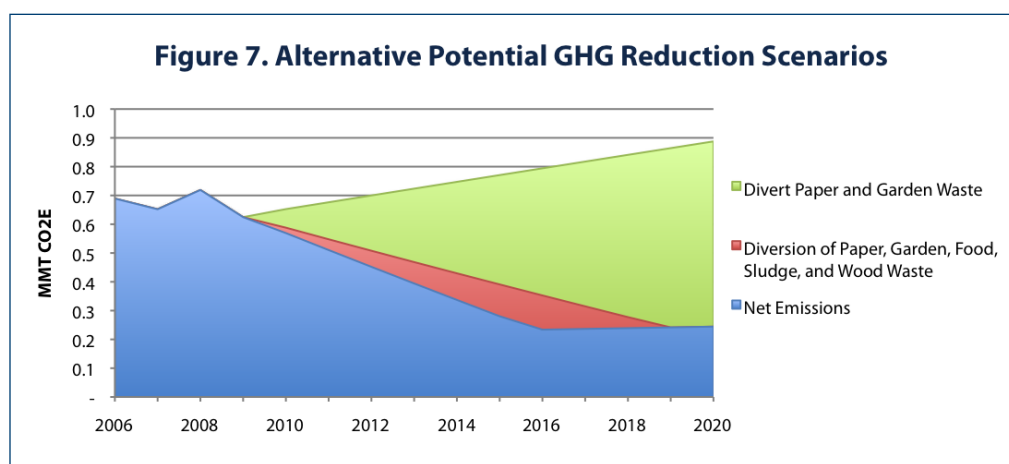
3.1. Increase Landfill Gas Capture Rates

The Discrete Early Action Reduction Measure approved by CARB under the wider mandate of AB 32 is to increase the capture of landfill gases in uncontrolled landfills, without specification of target capture levels. The average landfill gas capture rate in San Diego County between 1997 and 2007 has been 67%. Twenty out of twenty six landfills currently capture landfill gas. For the purposes of emissions reduction under the early action measure, it was assumed that it is feasible to increase the capture rate to 80% of the total production, or 13 percentage points more than the current average. (Figure 6)



3.2. Alternative Strategy: Diversion of Carbon Bearing Material

Although no other regulatory mechanisms are being considered for the reduction of landfill or wastewater treatment emissions, the effect of various potential strategies, which are practical and within reach, may be considered. Therefore, for example, if only the paper and garden waste components of carbon-



bearing waste were reduced to 1% of the total disposed, the resulting decrease in rapidly-degrading carbon-bearing materials and the reduction in the per capita waste disposed in landfills to about 1 metric ton can provide an emissions reduction wedge as shown in Figure 7. If nearly all components of carbon bearing waste (paper, garden waste, wood, food, sludge), which currently constitute more than 55% of the waste disposed, were diverted from landfills, the achievement of the 2050 target may become feasible. Figure 7 shows both these reduction strategies as wedges. The reductions caused by the diversion of carbon-bearing organic waste are eventually overshadowed by the increasing population effect on wastewater treatment emissions. This is the reason for the increase in emissions after about 2016, when wastewater treatment emissions become the driving force for the total waste category emissions.

The diversion of carbon-bearing wastes from landfills would require a re-evaluation of any current waste policies with its reliance on landfilling of waste. Whether it is technically, socially and economically more feasible to divert organic wastes for alternative energy-producing processes, or whether there is any potential to increase composting practices, or if in fact incineration of wastes is feasible given environmental regulations and concerns, are policy issues which warrant further research but are beyond the scope of this project.

4. Waste Sector Emissions Inventory Methodology

4.1 Domestic Wastewater Treatment Emissions

The project team estimated emissions from the domestic wastewater treatment by multiplying the per capita emissions factors for nitrous oxide (N_2O) and methane (CH_4) provided by the California Air Resources Board (Table 1).¹³ The emissions per person for N_2O have increased over the period of study while the methane emission factor per person has remained the same.¹⁴

Table 1. Waste Water Emissions Factors for Methane and Nitrous Oxide¹⁵

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CH4 emissions factor, wastewater treatment, grams/person	9855														
N2O emissions wastewater treatment grams/person	89.3	91	91	91	94	92	92	93	94	96	95	95	95	95	95

The CH₄ emissions factor is based on the Biochemical Oxygen Demand (BOD5)¹⁶ production rate of 0.1 kg BOD5/capita/day and a methane production capacity for domestic wastewater of 0.6 kg CH₄/kg BOD5. It also assumes an average CH₄ correction factor for treatment, or the anaerobically degradable fraction, for all treatment systems of 0.5.

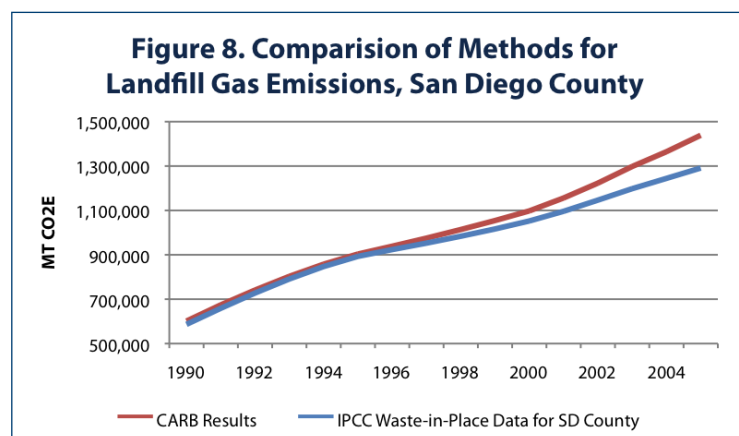
The biogas removed for combustion was provided by the Air Pollution Control District as millions of cubic feet of biogas produced per facility annually in the County. This was converted to mass of methane by assuming a density of biogas of 0.7 kg/m³, as provided by CARB. The data for biogas removed was available from 1997 to the present.

4.2. Landfill Gas Emissions

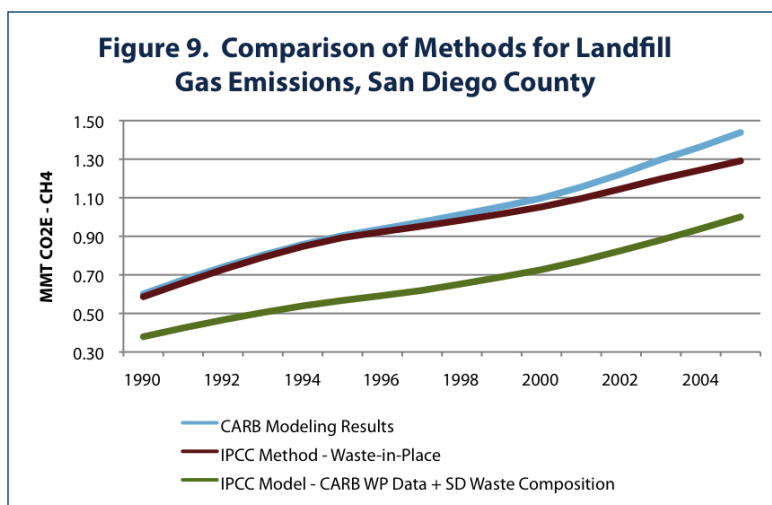
Since actual greenhouse gas emissions from landfills are not available, the project team relied on assumptions and models to calculate emissions based on waste disposed and the average composition of the waste disposed. The project team used the Mathematically Exact First Order Decay Model (FOD) from the IPCC Solid Waste Guidance Document.¹⁷ This model requires input of the amount disposed from 1950. Not all 26 landfills in the County existed in 1950, and even if they did, the data available does not go back as far as 1950. Some landfills opened and closed within the 1950 to 2005 time frame and others were open for waste disposal for less than a decade. The City of San Diego provided waste disposed data for four city landfills (out of the total 26 County landfills), of which the Miramar landfill is the longest operating, with data available from 1960. However, the Miramar landfill has not been the largest in the County. For other County landfills, only random spot data were found within site assessment reports available at the County Public Works Department. Therefore, it was not possible to use the local data available for the countywide amounts disposed.

The California Air Resources Board provided the waste disposed data for each of the 26 landfills in the County that it had obtained to carry out its GHG inventory. The data available to CARB had been back extrapolated and interpolated where there were data gaps using several complementary methods, as well as additional data available from CWIMB and US Environmental Protection Agency (US EPA) studies. The project team therefore used this countywide total disposal data as inputs to the IPCC model from 1950 to 2004.

The project team tested the closeness of agreement of the emissions results produced by the IPCC Waste model and the CARB calculations. Thus, the IPCC model was used with the CARB data using the parameters used by CARB for the state of California. For instance, the California average waste composition data was used, which is based on several EPA and CWIMB studies. The results of the IPCC Waste Model were found to be in close agreement with the results of raw methane emissions data provided by CARB (Figure 8) especially in the beginning years, but diverge up to 5% in the recent years. For the purpose of establishing the 1990 county level, this divergence is not of consequence but it will overestimate emissions of the forecasted values compared with any forecasts made by CARB using its values back to the 1930s.



The City of San Diego provided data on waste composition from studies carried out in 1996 and 2000. These show that the San Diego County waste profiles differ from the US EPA and CWIMB California-wide profiles, mainly in the lower content of organic matter. To account for this difference, the project team ran the IPCC Waste Model with the San Diego waste composition data and the CARB waste disposed data to obtain the results shown in Figure 9. These emissions values were used to determine the total carbon dioxide equivalents emissions from the landfill sector presented here.

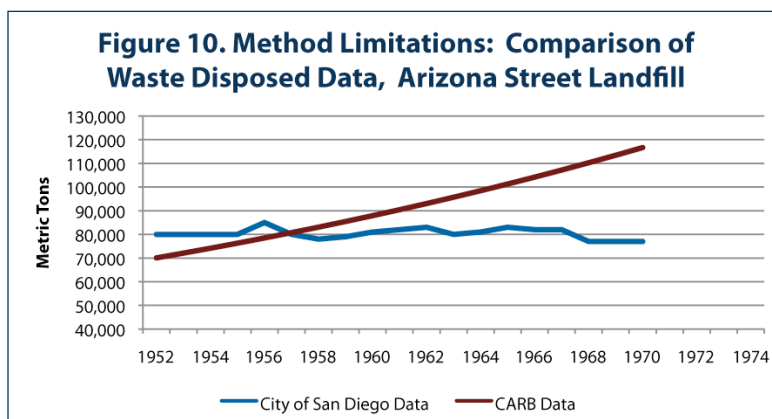


4.3 Method Limitations

Studies comparing modeling results with whole site methane emission measurements, though few, have shown that large differences in results occur depending on the model and when relying on backcast and interpolated data sets versus actual emissions.¹⁸ Therefore it is important that at least the same model and default parameters are used for comparison purposes, as done here. Still, large errors in estimation occur because of the lack or variations of actual waste disposed data, and lack of testing of the model with real landfill gas monitoring data.

For example, Figures 10-12 show a comparison of the waste disposed provided by CARB for three city landfills versus the data provided by the City of San Diego. The total waste in place in 2005 for the Miramar Landfill is only 10% different from that provided by CARB; however, the same comparison for the Chollas Landfill shows a difference of at least 50%. Other such comprehensive data was not available for the other landfills but similar differences might be expected.

Caution is needed even for this landfill specific comparison as both sets of data consist of backcast and interpolated values where there are data gaps. In this sense, a better comparison of the data differences may be obtained using the total waste disposed over the whole lifetime of any particular landfill, and not the distribution over the years or difference in any one year. A comparison of the total waste in place by 2005 for each of the city landfills showed that the total waste in place estimated by CARB versus that provided by the city, though both containing backcast and interpolated data, differ by only 10%. However, when the IPCC Waste Model is run with the CARB data and the City data, the annual differences flatten out, due to the nature of landfill degradation and long lag times (Figure 13).



Therefore, further improvement of the total waste disposed data might be possible from the total capacity of the landfill as given in the permits with the assumption that when the landfill closes, all its capacity has been used. However, to be consistent with CARB methodology, and due to lack of time and resources in this phase of the project, this method was not pursued further.

A second limitation is that waste composition varies not only between the state averages and San Diego County averages but also locally, among the county landfills. During the time of this study, it was not possible to find waste profile data for even all the existing active landfills. In addition, waste composition would have changed over the more than 50 years of disposal, while only two local studies are available, from 1996 and 2000, on waste composition.

As water is the determining factor for anaerobic decomposition, more accurate results would also be obtained if annual rainfall averages were used in place of one average value for all the years. For such reasons, the waste sector emissions, especially those from landfills, may be under- or even over-estimated.

A final limitation of the method is the lack of data for the amount of landfill and bio-gas captured from 1990. It appears from the data provided by CARB that at least one county landfill was combusting landfill gas in 1990 and some were operating from 1993. If similarly biogas were removed prior to 1996, the 1990 waste sector emissions estimate would be lower.

Figure 11. Method Limitations: Comparison of Waste Disposed Data, Chollas Landfill

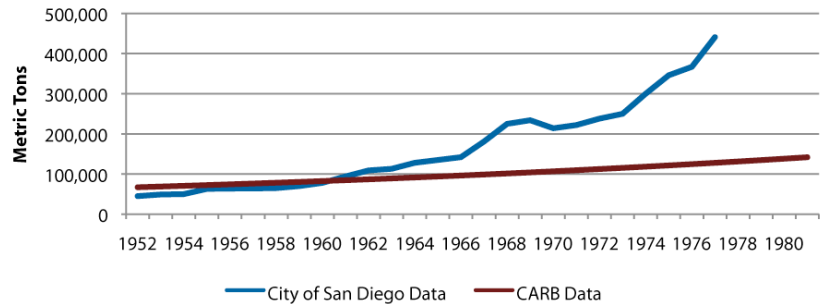


Figure 12. Method Limitations: Comparison of Waste Disposed Data, Miramar Landfill

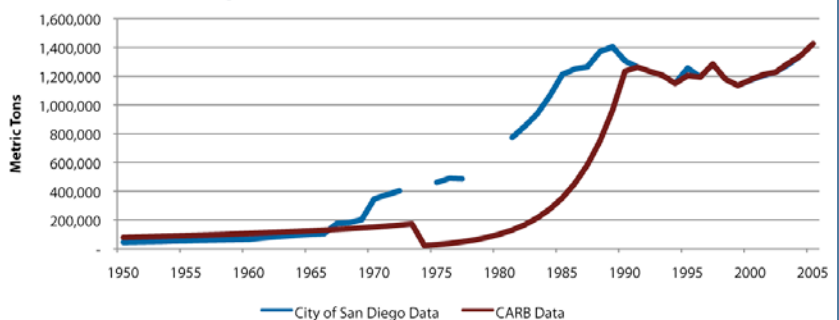
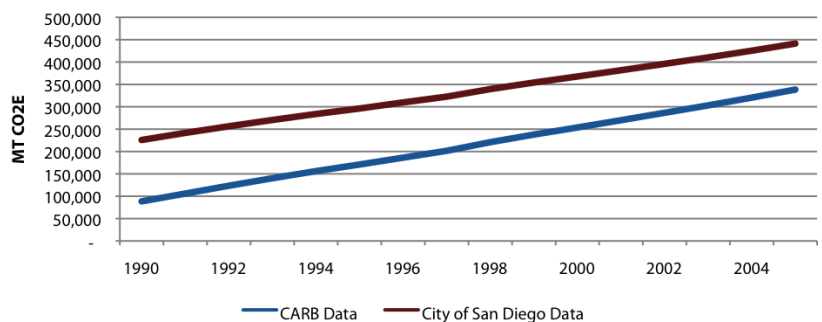


Figure 13. Comparison of IPCC Waste Model CO₂E-CH₄ Emissions Results for Miramar Landfill Based on City and CARB Waste Disposed Data



End Notes

1. See End Note 5.
2. The inventory is available from 1990-2004 at <http://www.arb.ca.gov/cc/inventory/data/data.htm>.
3. According to the national agricultural statistics 2002 Census data tables 11, 12, 13, 16, 29, there is little or no processing of agricultural products in San Diego County. See <http://www.nass.usda.gov/census/census02/volume1/ca/index2.htm>. This was confirmed by telephone communication with personnel at NASS.
4. Tchobanoglous G., Theisen H., Vigil S., Integrated Solid Waste Management, Engineering Principles and Management Issues, 1993, p. 381.
5. Greenhouse gas warming potentials (GWP) of 21 and 310 for methane and nitrous oxide respectively, were used to be consistent with the CARB 2004 inventory for California. The IPCC 2001 revised GWPs were 23 and 296 and the 2007 revised values are 25 and 298 over a 100 year lifetime. <http://ipcc-wg1.ucar.edu/wg1/wg1-report.html>, Chapter 2.
6. See End Note 4.
7. For a description of California waste law and AB 939 see <http://www.ciwmb.ca.gov/Statutes/Legislation/CalHist/1985to1989.htm>
8. San Diego County Integrated Waste Management Plan, Countywide Siting Element, 2005 5-Yr Revision.
9. Waste-in-place data to 2004 was obtained from CARB and is also available at the California Integrated Waste Management Board web page, annual tonnage reports (from 1996), at <http://www.ciwmb.ca.gov/Landfills/Tonnages/>
10. The total waste disposed in County landfills was 4,050,647 metric tons from a county population estimate by the US Census Bureau for 2005 of 2,936,607. A comparison with the US national waste disposal rates and other countries indicates the much larger amounts of waste generated and disposed in Southern California than most other places. The US national average for landfill disposal in 2006 was 761 kg per capita (EPA Solid Waste Fact Sheets, 2006, at <http://www.epa.gov/garbage/msw99.htm>). The national average for landfill disposal in Germany is less than 300 kg, and that in the city of Freiburg is 109 kg. Policy changes since the 1990s have led to these developments in Germany, and thus also to a decrease in landfill methane emissions to basically zero today. Thus the German Technical Instructions for Handling Waste 1993 required that waste containing only a minimum of organic material be thermally treated (incinerated) so as to be inert, before landfill disposal. At the same time, the most stringent BACT standards have been adopted for incineration facilities.
11. This is an average of the values from 1991 to 2004 provided in the California GHG Inventory at http://www.arb.ca.gov/cc/inventory/doc/docs4/4A1_Landfills_Landfillemissions_LandfillGas_N2O_2004.htm.
12. Miramar is the only active city landfill. Arizona Street and Chollas landfill are closed. One demonstration facility, Montgomery landfill, accepted solid waste from 1975 to 1990 but is excluded from the present inventory.
13. Personal communication with Mr. Lin Ying, CARB, 5 May 2008.
14. The increase in N₂O emissions has been attributed to the increase in consumption of red meat. See Volume 5, Waste, available at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/>
15. The methane factor was the latest (May 2008) provided by CARB.
16. The Biological or Biochemical Oxygen Demand is the amount of oxygen consumed by microbial oxidation of wastewater in a 5-day period. It is used as an indicator of wastewater “strength”. The BOD5 is proportional to the amount of organic matter in the water, and varies from country to country based on the quantity of water as well as diet.
17. The IPCC Waste Model available at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html>
18. Scharff, H., Jacobs, J., Applying Guidance for Methane Emission Estimation for Landfills, Waste Management, Volume 26, Issue 4, 2006, pp 417-429.



San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

Other Fuels Report

September 2008





Other Fuels Report

Acknowledgements

This project could not have happened without the generous support of the San Diego Foundation, San Diego Association of Governments, and NRG Energy, Inc.

Rebecca Kress contributed to this report. We would also like to thank Mary Bean for the graphic design of the report.

For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

This report presents estimated greenhouse gas (GHG) emissions for all fuels combusted or used in San Diego County but not accounted for in other sections of the San Diego County Greenhouse Gas Inventory, including distillate (other than in power production), coal (other than in power production), kerosene, gasoline (other than in transportation sector), LPG, residual fuel oil (other than in power production), and wood. Emissions from other fuel use are divided into the categories used by the California Air Resources Board (CARB) statewide greenhouse gas (GHG) inventory: household, energy, manufacturing, transport, commercial, agriculture, non-specified, and associated fugitive emissions. GHG emissions from these other fuel sources account for 4% of the overall GHG emissions for San Diego County.

This report provides estimates of other fuel emissions from 1990 through 2006 and projects future emissions through 2020.¹ Primary data was not available at the county level for the other fuels included in the CARB statewide inventory, so the project team used statewide data and scaled it to San Diego County using appropriate economic activity or population data.

1.1. Key Findings

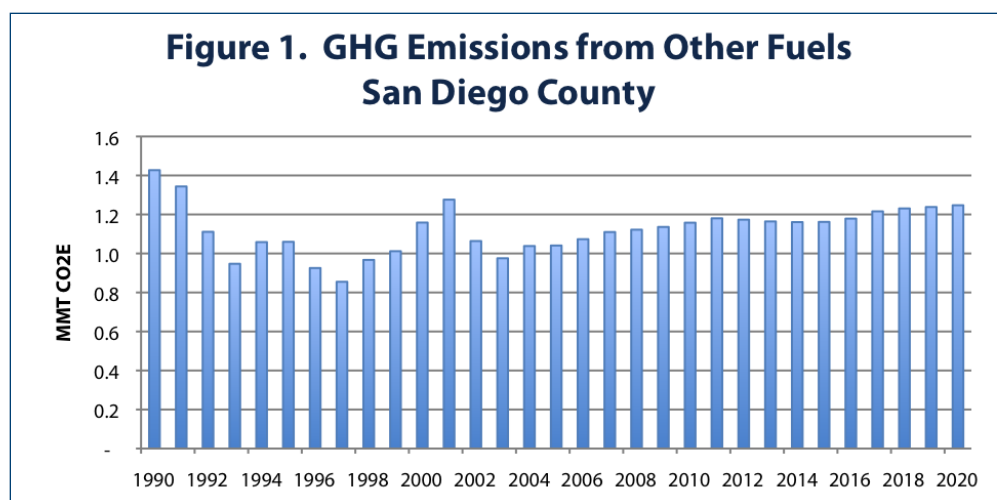
The key findings for the Other Fuels category include the following:

- In 2006, emissions from the Other Fuels category were estimated as 1.1 million metric tons carbon dioxide equivalent (MMT CO₂E), approximately 4% of overall regional GHG emissions, and about 24% less than the estimated 1990 level.
- The 1990 estimated baseline for the Other Fuels sector is 1.4 MMT CO₂E.
- The 2020 BAU forecast indicates a decreasing trend in this sector to 1.3 MMT CO₂E, or approximately 16% more than the 2006 levels, and 13% less than the 1990 levels.

2. Greenhouse Gas Emissions from Other Fuels

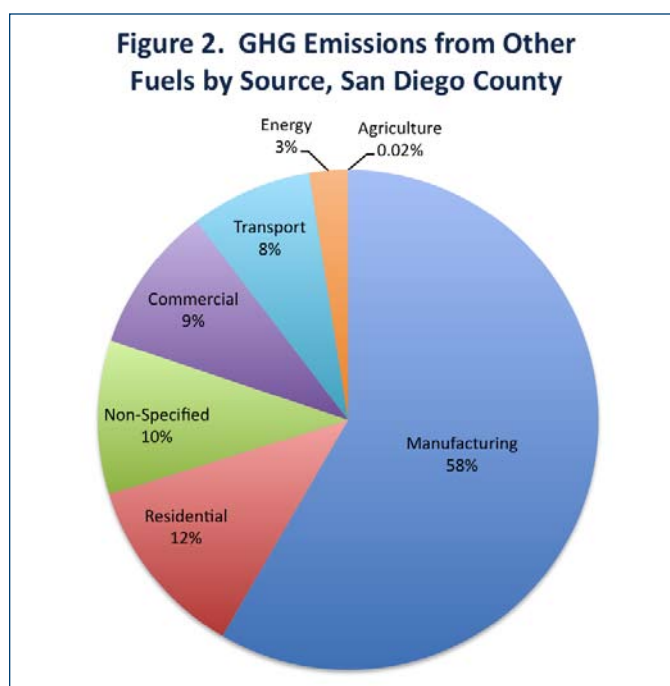
In 2006, GHG emissions from other fuel use in San Diego County were just over 1 MMT CO₂E, a 24% reduction below 1990 levels. Emissions in this category accounted for about 4% of total regional emissions in 2006. The business-as-usual projection for this category shows emissions increasing by 16% over 2006 levels by 2020, but remaining below 1990 levels (Figure 1).

Manufacturing is by far the dominant emissions source for this category, followed by residential, non-specified, commercial, and transportation (Figure 2).

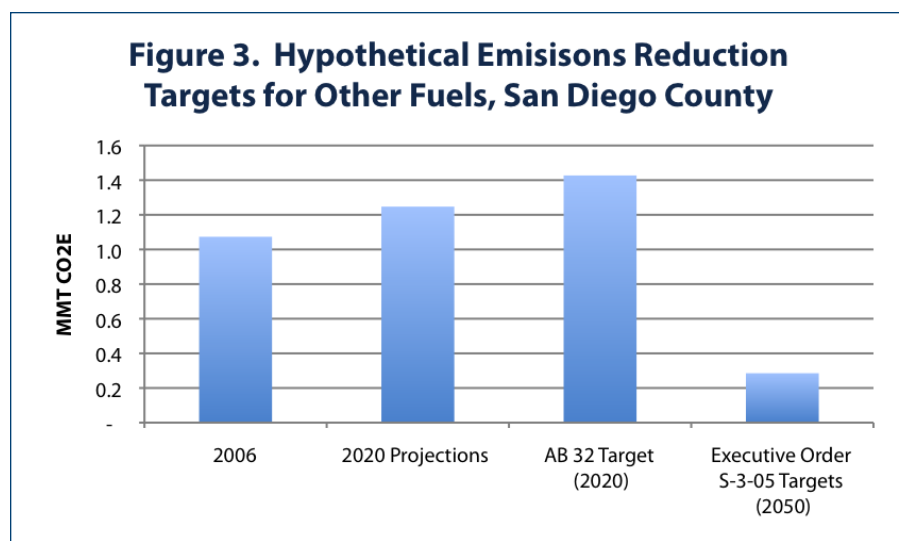


2.1. Emission Reduction Targets for the Other Fuels Category

In 2006 Governor Arnold Schwarzenegger signed into law the Global Warming Solutions Act (AB 32), establishing statutory limits on greenhouse gas emissions in California. AB 32 seeks to reduce statewide greenhouse gas emissions to 1990 levels by the year 2020. Even though AB 32 does not specify reduction targets for specific sectors or jurisdictions, this study calculated theoretical reductions targets as if the statewide statutory emissions reductions targets were applied to San Diego County and to each emitting category. According to the estimates presented above, GHG emissions from Other Fuels will be below 1990 levels by 2020; therefore, no emissions reductions strategies are provided here.



In 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes long-term targets for greenhouse gas emissions reductions. It seeks to reduce emissions levels 80% below 1990 levels by 2050. While this reduction target is not law, it is generally accepted as the long-term target to which California regulations are aiming. Similar to AB 32, Executive Order S-3-05 is intended to be a statewide target, but if applied hypothetically to San Diego County, total emissions from the Other Fuels sector would have to be reduced to 0.3 MMT CO₂E – a reduction of 0.96 MMT CO₂E (77%) below the 2020 business-as-usual forecast and 0.8 MMT CO₂E (73%) below 2006 levels. Figure 3 compares 2006 emissions levels, 2020 business-as-usual projections, AB 32 and Executive Order S-3-05 targets.



3. Other Fuels Methodology

The project team used data from the CARB statewide greenhouse gas inventory to derive regional emissions estimates. In general, statewide emissions values were scaled to San Diego County using data on relevant economic activity or population data.² The following categories are included in the Other Fuels emissions estimate: household use; energy - petroleum marketing; manufacturing for non-metallic minerals, oil and natural gas, construction, and non-specified; transportation for non-specified; commercial non-specified; agriculture energy use; and non-specified Industry. Emissions associated with rail are accounted for in a separate category and described in the Other Transportation Report.

3.1. IPCC Categories Not Included

Several categories were included in the CARB statewide inventory but not included in our estimate for San Diego County. Emissions from the following IPCC categories were set to zero because Economic Census data from 1997 and 2002 from the US Census Bureau indicated no economic activity in San Diego County:

- 1A1b - Petroleum Refining >
 - Associated gas > CH₄, CO₂, N₂O
 - Catalyst Coke > CH₄, CO₂, N₂O
 - Distillate > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O
 - Petroleum Coke > CH₄, CO₂, N₂O
 - Refinery Gas > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O

- 1A1c - Manufacture of Solid Fuels and Other Energy Industries > Oil & Gas Extraction >
 - Associated gas > CH₄, CO₂, N₂O
 - Crude oil > CH₄, CO₂, N₂O
 - Distillate > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O
- 1B2 - Oil and Natural Gas > Manufacturing : Stone, Clay, Glass & Cement : Fugitives > Fugitive emissions > CH₄
- 1B2 - Oil and Natural Gas > Manufacturing : Construction : Fugitives > Fugitive emissions > CH₄
- 1B2 - Oil and Natural Gas > Manufacturing : Storage Tanks : Fugitives > Fugitive emissions > CH₄
- 1B2a – Oil > Petroleum Refining : Process Losses : Fugitives > Fugitive emissions > CH₄
- 1B2a – Oil > Petroleum Refining : Storage Tanks : Fugitives > Fugitive emissions > CH₄
- 1B3 - Other Emissions from Energy Production > In State Generation : Merchant Owned > Geothermal power - Geothermal > CO₂
- 1B3 - Other Emissions from Energy Production > In State Generation : Utility Owned > Geothermal power - Geothermal > CO₂

3.2. IPCC Categories Included

Emissions from the following category are taken from the California state inventory (CARB, 2007) and scaled to San Diego County using gross income from agriculture production for the years 1999 and 2000. The data for the state of California and San Diego County are from the California Energy Commission.³

- 1A4c - Agriculture/Forestry/Fishing/Fish Farms > Ag Energy Use
 - Distillate > CH₄, CO₂, N₂O
 - Kerosene > CH₄, CO₂, N₂O
 - Gasoline > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O

These emissions are taken from the California state inventory (CARB, 2007) and scaled to San Diego County using population data. Annual population data is from the US Census Bureau.

- 1A4b – Residential > Household Use
 - Distillate > CH₄, CO₂, N₂O
 - Kerosene > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O
 - Wood (Wet) > CH₄, N₂O

The following emissions were calculated by scaling the California state inventory (CARB, 2007) data for each sector to the San Diego County level by using population data from the US Census Bureau (2002).

- 1A2f - Non-Metallic Minerals > Manufacturing : Stone, Clay, Glass & Cement : Cement >
 - Biomass Waste Fuel > CH₄, N₂O
 - Coal > CH₄, CO₂, N₂O
 - Distillate > CH₄, CO₂, N₂O
 - Fossil Waste Fuel > CH₄, CO₂, N₂O
 - Petroleum Coke > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O
 - Tires > CH₄, CO₂, N₂O
- 1A2m - Non-specified Industry > Manufacturing >
 - Coal > CH₄, CO₂, N₂O
 - Distillate > CH₄, CO₂, N₂O
 - Kerosene > CH₄, CO₂, N₂O
 - Gasoline > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O
 - Natural Gas Liquids > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O
- 1A2m - Non-specified Industry > Not Specified Industrial - Wood (Wet) > CH₄, N₂O
- 1A2k – Construction > Manufacturing : Construction - Gasoline > CH₄, CO₂, N₂O
- 1A5 - Non-Specified > Not Specified Not Specified - LPG > CH₄, CO₂, N₂O
- 1B2 - Oil and Natural Gas > Manufacturing >
 - Electric & Electronic Equip. : Fugitives > Fugitive emissions > CH₄
 - Food Products : Fugitives > Fugitive emissions > CH₄
 - Plastics & Rubber : Fugitives > Fugitive emissions > CH₄
 - Primary Metals : Fugitives > Fugitive emissions > CH₄
 - Pulp & Paper : Fugitives > Fugitive emissions > CH₄
 - Stone, Clay, Glass & Cement : Fugitives > Fugitive emissions > CH₄
 - Chemicals & Allied Products : Fugitives > Fugitive emissions > CH₄
 - Primary Metals : Fugitives > Fugitive emissions > CH₄

The following emissions were calculated by scaling the statewide emissions (CARB, 2007) to the San Diego County level using economic data from the US Economic Census 2002 date for Retail Trade, Real Estate/ Rental Services, Arts/Entertainment, and Accommodations/Food.

- 1A4a - Commercial/Institutional > Not Specified Commercial
 - Distillate > CH₄, CO₂, N₂O
 - Coal > CH₄, CO₂, N₂O
 - Kerosene > CH₄, CO₂, N₂O
 - Gasoline > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O
 - Wood (Wet) > CH₄, N₂O

Emissions in the following category were scaled from the statewide inventory (CARB, 2007) based on the total annual vehicle miles traveled in 1990, 1995, 2000, 2005, and 2006 as estimated by the California Department of Transportation.⁴ Ratios in intervening years were linearly extrapolated.

- 21A3 – Transport > Not Specified Transportation >
 - Distillate > CH₄, CO₂, N₂O
 - LPG > CH₄, CO₂, N₂O
 - Residual Fuel Oil > CH₄, CO₂, N₂O

The following emissions were scaled from statewide levels using the ratio of the total On-Road emissions of San Diego County divided by California On Road emissions.

- 1B2 - Oil and Natural Gas > Petroleum Marketing : Process Losses : Fugitives > Fugitive emissions > CH₄
- 1B2 - Oil and Natural Gas > Petroleum Marketing : Storage Tanks : Fugitives > Fugitive emissions > CH₄

End Notes

1. This section includes only emissions from “other fuels.” A small amount of emissions due to cogeneration are included in the main category of Other/Other Fuels. Information about cogeneration can be found in the Electricity Report.
2. Gross economic data for the agriculture sector is available at: <http://www.energy.ca.gov/research/iaw/industry/agri.html>. Economic Census data is available at: http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=04000US06&-ds_name=EC0200A1&-_lang=en and http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=31000US41740&-ds_name=EC0200A1&-_lang=en. Population data is available at: http://factfinder.census.gov/servlet/ACSSAFFPeople?_submenuId=people_1&-sse=on.
3. Go to: <http://www.energy.ca.gov/research/iaw/industry/agri.html>
4. Available at: <http://www.dot.ca.gov/hq/tsip/smb/documents/mvstaff/mvstaff60.pdf>



San Diego County Greenhouse Gas Inventory

An Analysis of Regional Emissions and
Strategies to Achieve AB 32 Targets

Agriculture, Forestry, and Land Use Report

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September 2008





Agriculture, Forestry, and Land Use Report

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For an electronic copy of this report and the full documentation of the San Diego Greenhouse Gas Inventory project, go to www.sandiego.edu/epic/ghginventory.

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1. Introduction

Agriculture, forestry, and other land-based activities may both absorb and emit greenhouse gases (GHG). This category is one of the main categories used in the California Air Resources Board (CARB) statewide inventory, which followed the Intergovernmental Panel on Climate Change protocols. This report, a component of the San Diego County Greenhouse Gas Inventory project, follows the CARB format and provides an estimate of historical and projected GHG emissions from the following two subcategories:

- **Livestock Management**– This includes emissions from both enteric fermentation and manure management.
- **Sequestration by Land Cover** –This is the net level of greenhouse gas emissions from CO₂ uptake by plant growth (sinks) and greenhouse gas releases from the destruction of existing land cover (vegetation). Our analysis includes the total amount of greenhouse gases sequestered by natural vegetation in San Diego County, the effects of development on sequestration, and emissions from wildfires during the period 1990 to 2007.

The subcategory of crop burning and soils management, which includes non-CO₂ emissions from agricultural activities, is a component of the agriculture, forestry, and other land-based activities category in the CARB statewide inventory; however, due to a lack of data – and the likelihood that emissions will be relatively very small – emissions from these activities are not included in the analysis here.

Taken together, the emissions from the above categories in San Diego County were negative in most years from 1990-2006; that is, emissions from the agricultural sector, development, and wildfires were typically offset by sequestration. Only in years with higher than average wildfires were there net positive emissions from this category. Table 1 includes emissions data for selected years. The years 2003 and 2007 are shown to demonstrate the effects that large firestorms have on greenhouse gas emissions in the region.

Table 1. Emissions from Agriculture, Forestry, and Land Use Category (MMT CO₂E)

Category	1990	1995	2000	2003	2005	2007	2020
Livestock	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Sequestration from Land Cover	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)
Emissions from Development	0.1	0.1	0.2	0.3	0.2	0.2	0.2
Wildfires*	0.2	0.6	0.2	7.8	0.3	5.8	0.3
Total Emissions	(0.3)	0.1	(0.2)	7.5	(0.1)	5.4	(0.2)

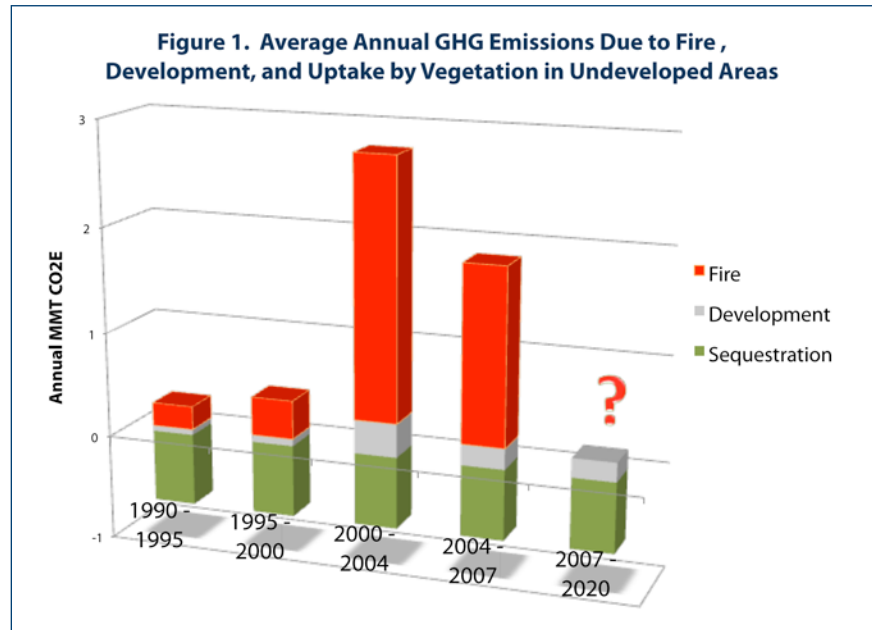
*2005 and 2020 wildfire numbers are estimates. No data was available for 2005.

Presented below are key findings from this section and more detailed summaries of each section, including an explanation of the methods used to calculate the emissions estimates for this sector.

1.1. Key Findings from the Agriculture, Forestry, and Other Land Use Category

- Largely because of two catastrophic firestorms, plant growth, fires, and development taken together over the entire period 1990 – 2007 caused a net loss of biomass in San Diego County and the corresponding release of 7 MMT CO₂. This corresponds to an average annual release of 0.4 MMT CO₂ / yr. Figure 1 demonstrates this trend.

- During the 1990s there was a net increase in plant biomass as carbon uptake due to plant growth outpaced releases due to fires and development. On the average, 0.3 MMT CO₂ was removed from the atmosphere each year during this period.
- During the period 2000 – 2007 there was a significant loss of biomass (and an increase in CO₂ emissions) due to firestorms and an increased rate of development, more than offsetting sequestration during the 1990s.
- In 2006, land cover in undeveloped areas sequestered approximately 0.7 MMT CO₂ in San Diego County, down slightly (by 2.5%) from 1990 levels due to development.
- During the period 1990 – 2020, an additional 7.5% of the County land area is projected to be developed for agricultural or urban uses. This development will reduce the CO₂ uptake by native vegetation by 5%.¹
- The 3% of county land that is forested is responsible for 34% of the CO₂ uptake by vegetation.
- Livestock management accounts for 0.2% of overall regional GHG emissions. According to projections, without any changes to current trends, agricultural emissions are expected to decline further to insignificant levels by 2020.



2. Sequestration By Land Cover

Land use effects greenhouse gas levels via several processes. Carbon dioxide is taken up by growing plants, and released again by decomposing plant matter displaced by development. During wildfires, carbon dioxide, nitrous oxide, and methane are released. The amount of gases involved in these processes depends primarily on the type of ecosystems involved. The classes of vegetation in San Diego County and their relative coverage are shown in Figure 2.

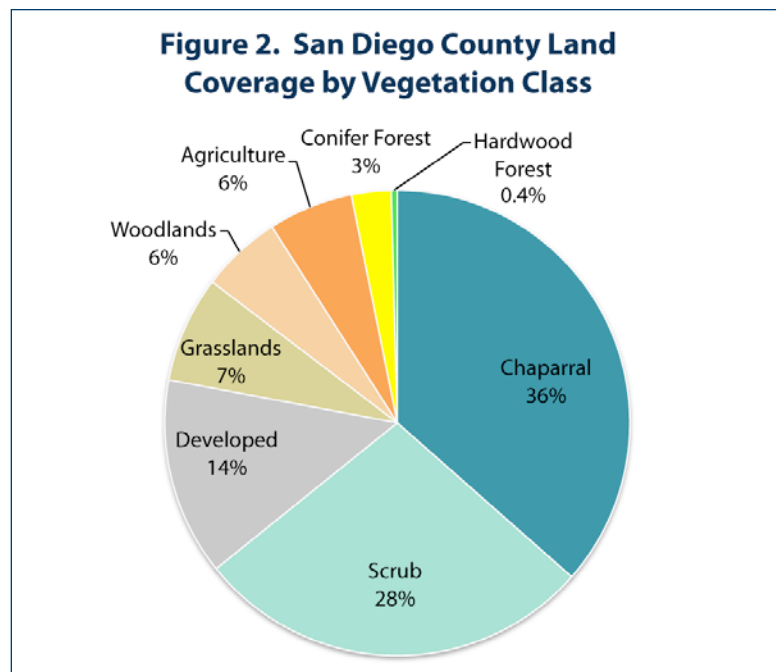


Figure 3
Vegetation
of San Diego
County
(1995)³

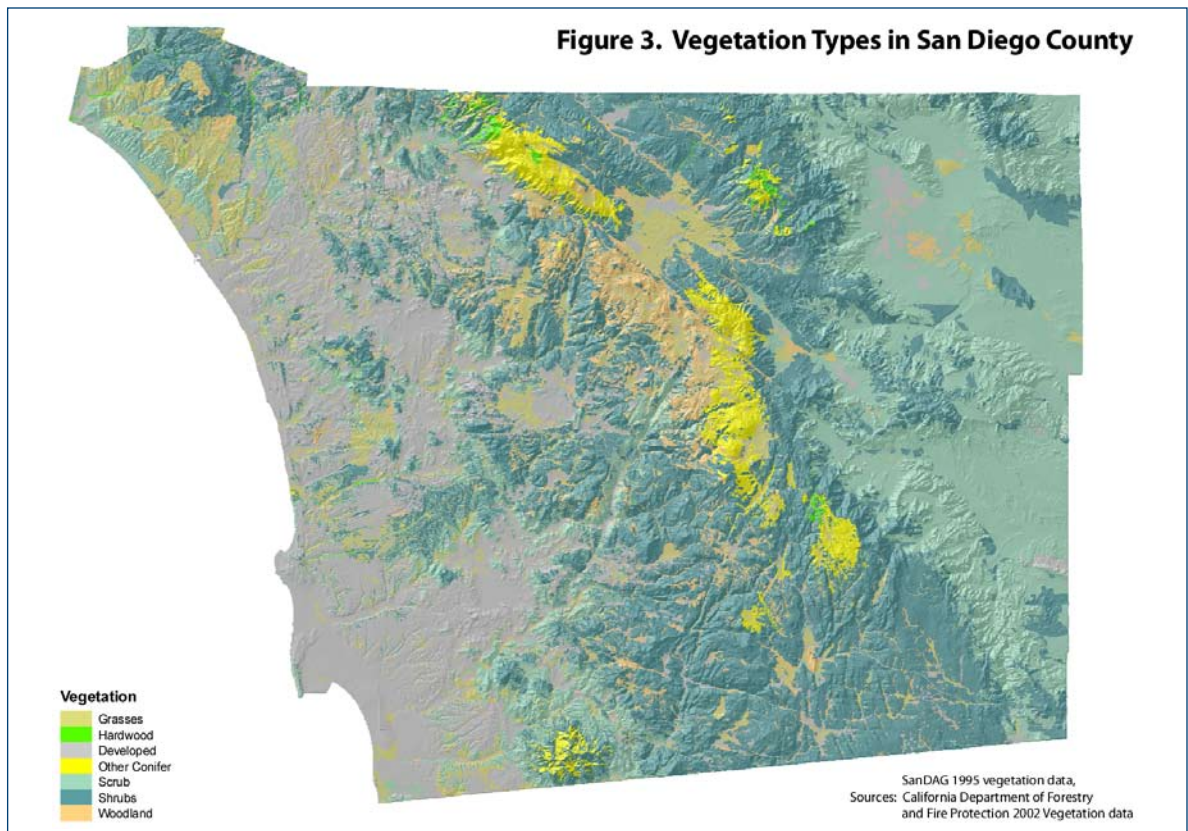
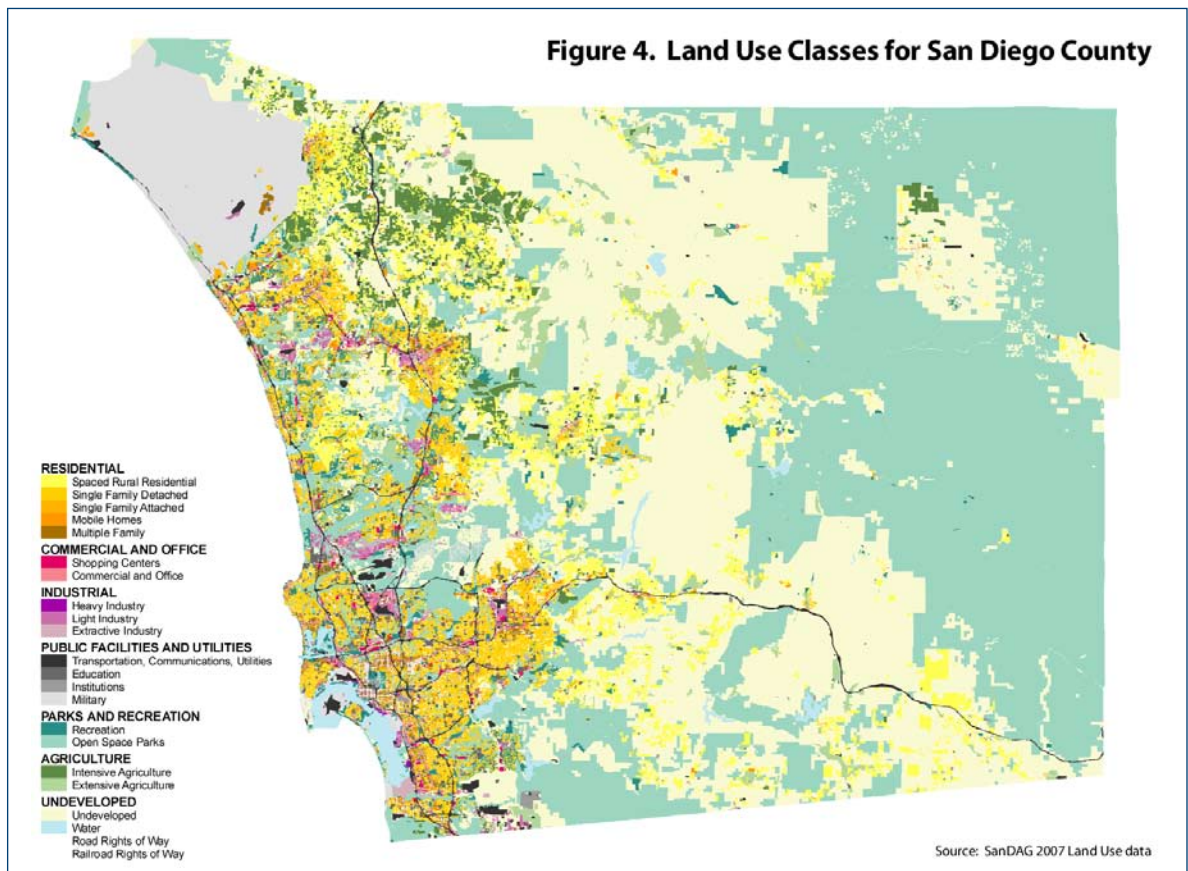


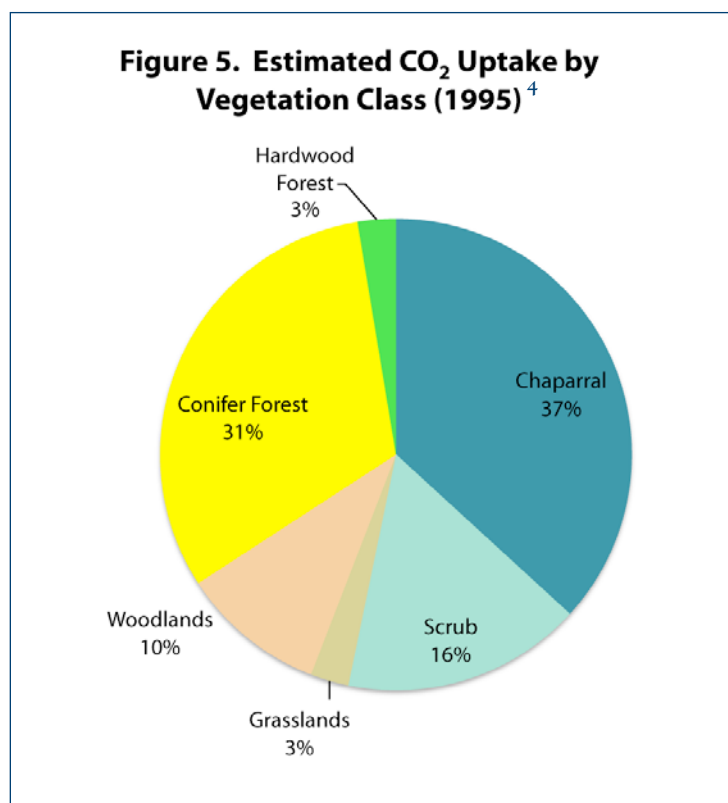
Figure 4
Land Use
San Diego
County
(2007)



Figures 3 and 4 show maps of the vegetation areas, developed using GIS analysis of data from SANDAG and the California Department of Forestry and Fire Protection. Spatial analysis of this data reveals that only 3% of county land is forested, while another 6% is woodland (a mixture of grass and well-spaced trees). Chaparral, scrub, and grasslands are the predominant vegetation types, covering over 70% of county land area. Just less than 14% was developed in 1995, and the remaining 6% is agricultural land, predominantly orchards.² Our classification of a variety of ecosystem types into these categories is summarized in Section 2.5.

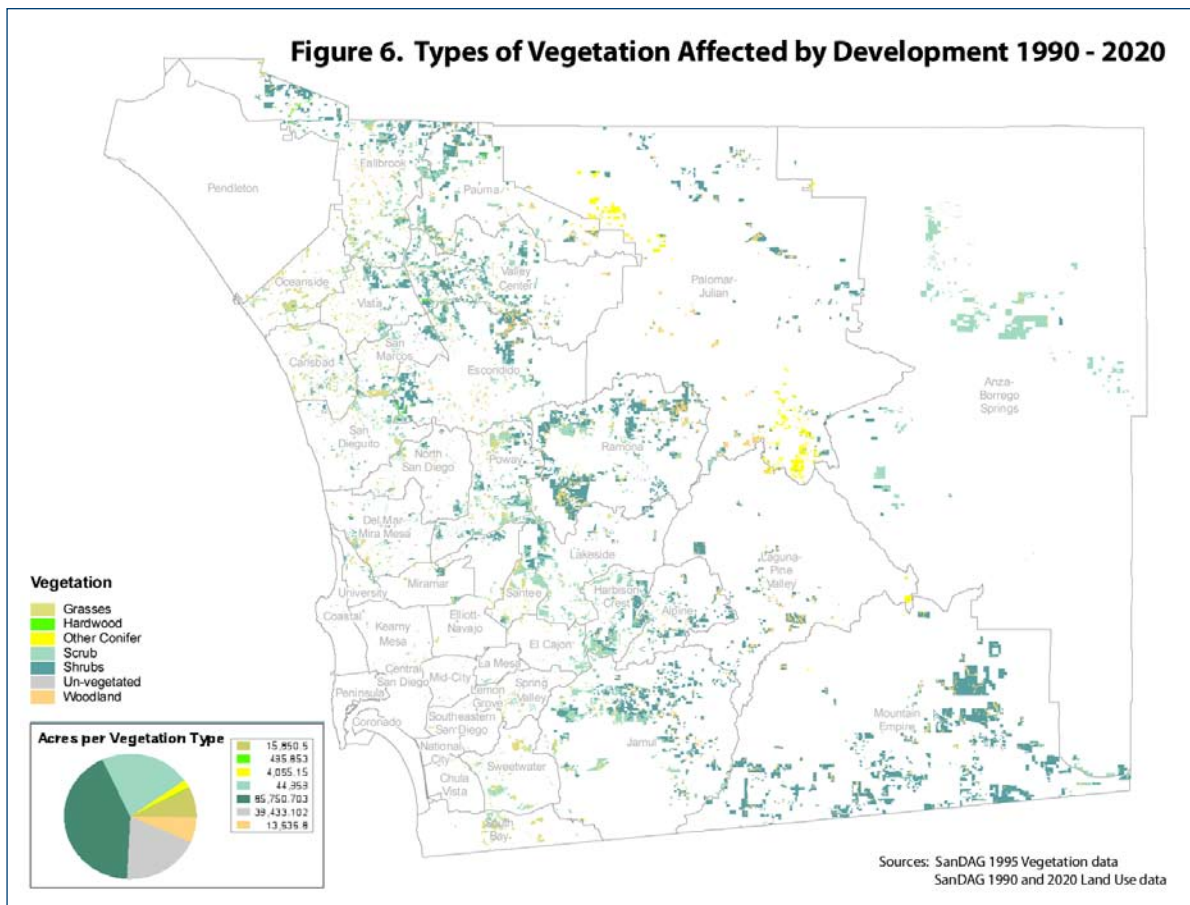
2.1. Emissions Sequestered by Land Cover

The carbon uptake rates of each class of ecosystem are listed in Section 2.5. Developed and agricultural lands are excluded from this analysis. (Note that total agricultural biomass in the county is decreasing.) In 1995, 0.7 MMT CO₂ was sequestered by vegetation in undeveloped areas in San Diego County. Other yearly totals are listed in the inventory. Because of higher rates of CO₂ uptake by forests, chaparral and conifer / hardwood forests contribute almost equally to this total, with chaparral accounting for 37% and forests for 34% of carbon uptake. Chaparral, scrub, and grasslands were ignored in the California Air Resources Board statewide GHG inventory due to the substantial forested areas of the Sierra Nevada, the Coast Range, and Northern California. However, we estimate that these ecosystems together are responsible for well over half of the total carbon uptake in San Diego County.



2.2. The Effect of Development on Land Cover Sequestration

During the period 1990 – 2020, it is projected that a total of 7.5% of San Diego County land area will have been converted from undeveloped into agricultural and developed land use categories (Figure 6).⁵ Development has two effects on greenhouse gases via vegetation. First, it directly releases carbon stored in displaced vegetation as CO₂. The amounts of carbon stored by each vegetation class are listed in Section 2.5. Second, it reduces the amount of net uptake in subsequent years.

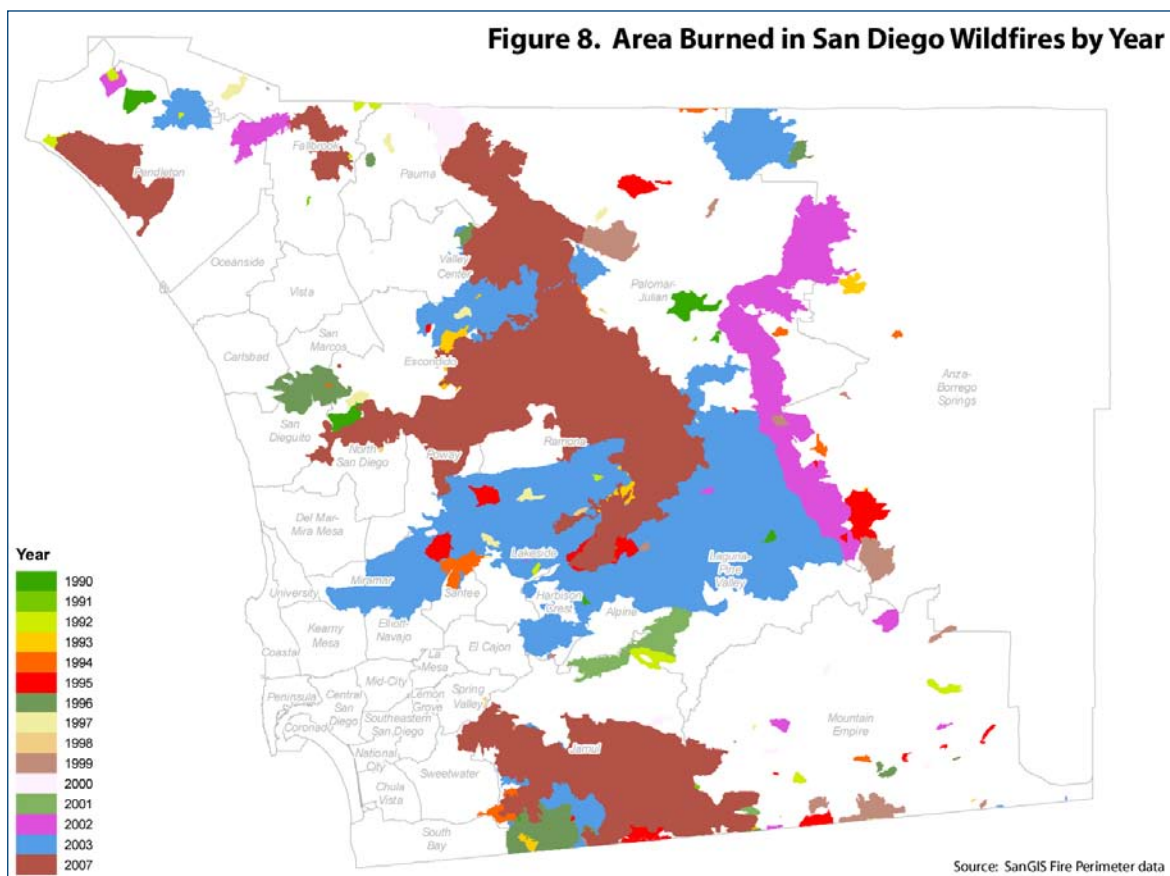
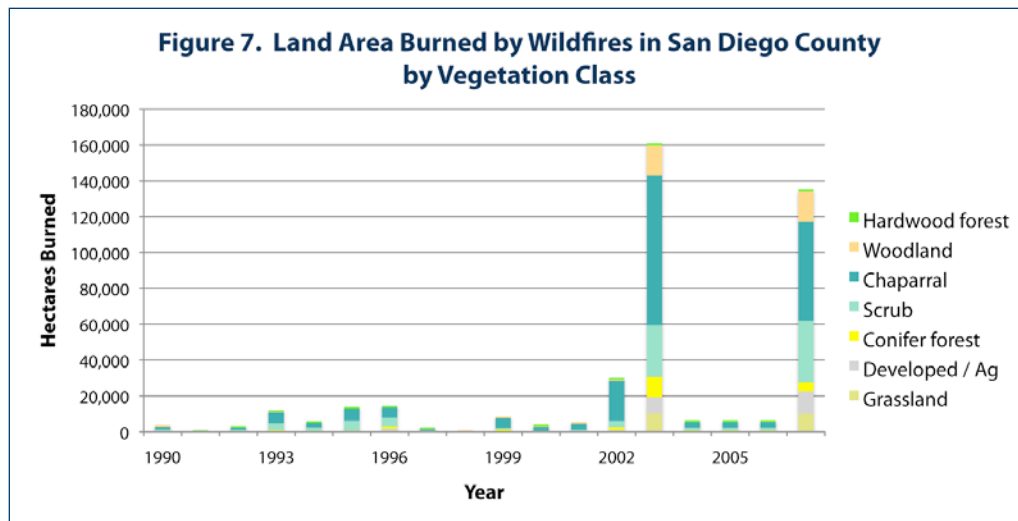


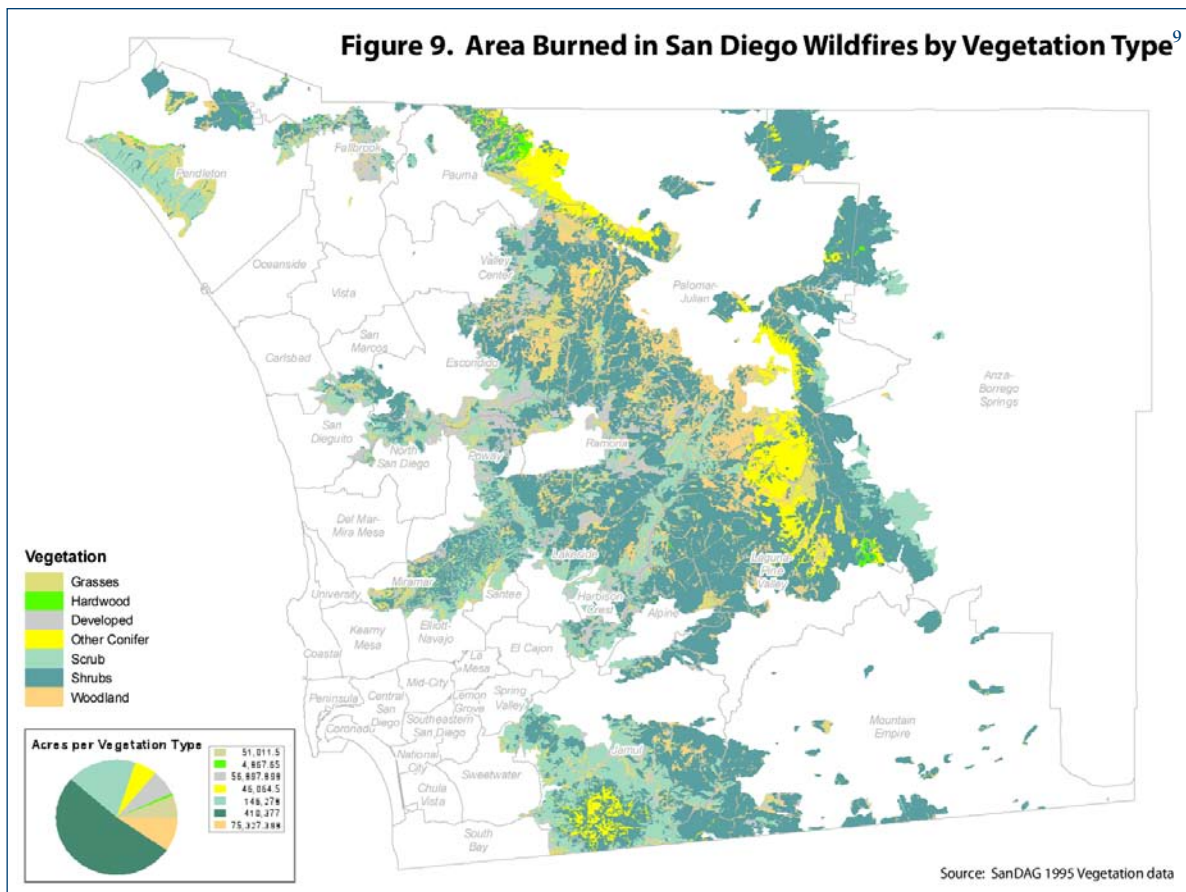
Spatial analysis of the data shown above indicates that over the period 1990 – 2020 an average of 0.132 MMT CO₂ is released annually from biomass removed to make way for development (or agriculture). This counteracts about 20% of the total CO₂ uptake by vegetation and reduces the vegetated areas that can absorb CO₂ in the future. Because development occurs disproportionately away from forested areas in San Diego County, the reduction in CO₂ uptake by native vegetation during the period 1990 – 2020 is estimated to be 5% (rather than 7.5%).

More detailed analysis of SANDAG land use data from 1990, 1995, 2000, 2004, 2007, and 2020 (projected) indicates that development occurs at uneven rates, corresponding with local economic cycles.

2.3. Emissions Due to Fires

Analysis of charcoal in coastal ocean sediments off of Santa Barbara, California, indicates that over the past six centuries, at least 20 large firestorms have burned in that region.⁶ Two to five firestorms per century have occurred since 1425, and this rate is probably typical for the entire coastal Southern California region. Firestorms have affected Southern California twice in the last decade. GIS burn area data for 1990 to 2003 and 2007⁷ was combined with vegetation data from the previous section to determine amounts of each type of land cover burned each year. Figures 7 – 9 summarize this data.⁸

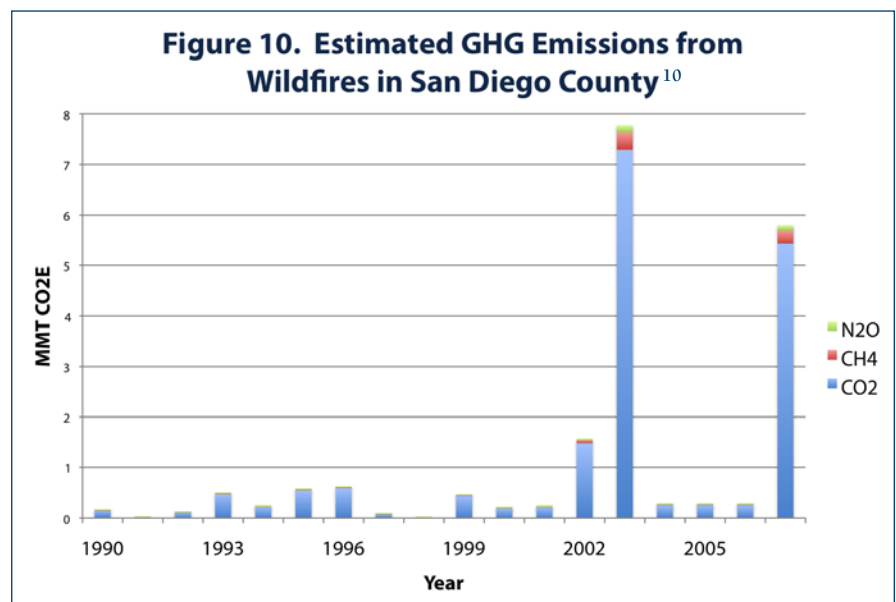




The burn areas of the firestorms in the county in 2003 and 2007 were each about 10 times larger than annual totals seen during the non-firestorm years 1990 – 2001.

A summary of yearly fire emissions is shown in Figure 10. The method of Wiedinmyer (2006) was adapted to make these estimates, as summarized in Section 2.5. The 2003 firestorm was slightly larger in size and burned more heavily vegetated areas than the 2007 firestorm, resulting in a larger loss of county biomass and greater emissions. The two firestorms together released a total of 14 MMT CO₂E (mostly as CO₂). Thus, two full decades of CO₂ uptake by vegetation were reversed in only two weeks of disastrous fires.

It is not yet possible to predict the severity of future fire seasons, and we cannot conclude that there has been a change in fire frequency based on two recent firestorms. However, if the local climate should change and become either hotter, drier, or both, the severity of fires would be expected to increase, making long-term carbon sequestration through plant growth in undeveloped areas a challenge.



2.4. Greenhouse Gas Reduction Strategies

There are three possible strategies for minimizing the negative impact of development and restoring carbon uptake by plant growth to 1990 levels. First, urban growth could be directed away from high-biomass ecosystems: chaparral, woodlands, and especially forests. Second, programs encouraging tree planting and preservation in the urban area (“urban forestry”) could be launched. Finally, fire ignition prevention efforts and firefighting capabilities could be increased to limit the extent of future wildfires while maximizing carbon biomass. The effects of these three actions are quantified below.

If zoning laws were changed to require that 75% of living tree biomass be preserved during development of forest and woodland parcels (or if the development of 75% of these parcels is redirected to low biomass ecosystems), the biomass equivalent to 0.3 MMT CO₂ would be preserved during the period 2007 – 2020, which equals 0.03 MMT CO₂E annually. In addition, the annual CO₂ uptake in 2020 would be larger by 0.005 MMT CO₂, for a total reduction in 2020 of 0.03 MMT CO₂E.

We have not included the effects of urban forestry thus far in our analysis of carbon sequestration due to lack of data. However, we estimate that an additional 10% of the developed area in San Diego County could be converted to the equivalent of woodlands by 2020 through a vigorous urban forestry program. The resulting increase in vegetation would result in 0.02 MMT CO₂ of additional uptake, with more benefits by 2050. Increased shade provided by these trees could reduce the demand for air conditioning, and the corresponding electricity consumption, at some locations. However, this benefit has not been quantified.

Once fires start during strong Santa Ana conditions, containment has proven to be extremely difficult. Attempts to limit ignitions through backcountry closures and strategic power line deactivation during times of extreme fire danger could reduce the likelihood of future firestorms. Fuels management, while successful in maximizing biomass in forested regions, may not be effective for the chaparral and scrub ecosystems common in San Diego County. The environmental benefits of preventing firestorms cannot be quantified considering the natural variability in wildfire frequency and extent. However, success in preventing firestorms and thereby increasing the carbon biomass of natural areas would be a significant help in limiting the buildup of atmospheric carbon dioxide.

2.5. Methodology

Carbon uptake by vegetation was estimated using CARB methods (Winrock¹¹) for forests, woodlands, and riparian environments, which are dominant in carbon uptake at the state level. However, because these ecosystem types are rare in San Diego County, other types of ecosystems that were ignored in the CARB California statewide GHG inventory, namely scrub, chaparral, and grasslands, play a significant role here.

San Diego County vegetation data was downloaded as GIS shapefiles from the SANDAG website.¹² Data from outside the county border was removed. Data gaps in the eastern third of the county were filled in using 2002 raster data with 100 m resolution from the California Department of Forestry and Fire Protection.¹³ Due to limited resolution, these data sets do not include information on urban trees unless they are in parks or open space preserves. The 130 vegetation types in the SANDAG dataset were re-categorized into the 7 classes listed in Table 5. “Scrub” is a new class; other classes are used in the CARB (Winrock) study. Ecosystem types classified as scrub include coastal sage scrub and Sonoran desert scrub. Most of the classifications are either obvious or were specified in the CARB (Winrock) study. Other broadleaf ecosystems were classified as hardwood forest or woodland depending on typical tree size and density, with the higher woody biomass ecosystems classified as hardwood forest.

Table 2: Ecosystem Classification System Used in this Study.

Holland Vegetation Code	Holland Description	Winrock Classification
11100	Eucalyptus Woodland	Woodland
11200 – 11300	Non-native, disturbed	Grassland
12000	Urban / Developed	Unvegetated
13100 – 24000	Unvegetated, agricultural, and dunes	Unvegetated
29000 – 36120	Scrub	Scrub ¹⁴
37000 – 39000	Chaparral	Shrubs ¹⁵
42000 – 52440	Grasslands, marshes	Grasslands
60000 – 61000, 62400	Riparian bottomland forest / sycamore – alder	Hardwood forest
61300 – 62000, 63810	Riparian oak / cottonwood / mesquite / tamarisk	Woodland
62200, 63300 - 63310	Riparian scrub, drywash	Scrub
63320	Riparian willow	Shrubs
71000 – 71182, 77000 - 79000	Woodlands, oak	Woodland
72300-72320	Woodlands, pinyon / juniper	Shrubs ¹⁵
81100, 83140 – 85100	Forest, evergreen	Conifer forest
81300, 81340	Forest, black oak	Hardwood forest
81310 – 81320	Forest, live oak	Woodland

Table 3 lists carbon uptake rates, biomass amounts, and fire emissions data for the seven classes of land cover in San Diego County. The uptake rates for hardwood forests, conifer forests, and woodlands were specified in the CARB (Winrock) study. Other uptake rates had to be estimated from other sources. Annual carbon uptake rates for chaparral and grassland ecosystems were estimated to be 0.9% and 1.2%, respectively, of the total carbon stock in each ecosystem type, estimated using biomass data taken from Wiedinmyer et al.¹⁶ (2006) and shown in the fuel loading column. (Chaparral was assigned to the “shrubland” category. A 44.4% carbon content in shrubland and grassland biomass was taken from Wiedinmyer et al.) For chaparral, this amount of carbon uptake matches integrated field measurements performed on young and on mature local chaparral ecosystems by Luo.¹⁷ Since grasslands reach maturity sooner, a slightly higher percentage (1.2%) of total carbon stock was used to estimate annual carbon uptake rates. Since scrub is in between grassland and shrub / chaparral in terms of the amount of biomass present, values for carbon uptake and biomass were selected that were in between the other two categories but closer to grasslands.

Table 3: Carbon Uptake, Biomass, and Fire Emission Data for San Diego County Ecosystems (All tons are metric)

Ecosystem Type	Carbon Accumulation Rate	Fuel Loading <i>B</i>	Woody Fraction <i>w</i>	Combustion Efficiency <i>E</i>		Emission Factors <i>F</i>		
	ton C / ha yr	ton biomass /ha		woody	herbaceous	kg CO ₂ / ton biomass burned	kg CH ₄ / ton biomass burned	kg N ₂ O / ton C released
Hardwood Forest	1.05	120	0.85	0.3	0.9	1569	4.5	0.079
Conifer Forest	1.93	140	0.79	0.3	0.9	1569	4.8	0.079
Woodlands	0.3	95	0.84	0.3	0.98	1569	4.5	0.079
Chaparral	0.17	43	0.39	0.3	0.98	1630	3.1	0.079
Scrub	0.1	20	0.2	0.3	0.98	1630	3.1	0.079
Grasslands	0.06	11	0.08	0.3	0.98	1630	3.1	0.079
Unvegetated	0	0	na	na	na	na	na	na

Annual carbon uptake by each type of land cover was calculated by multiplying its land area in a given year times the appropriate uptake rate listed in the table. We have assumed that over the period 1990 – 2007 developed lands and agricultural lands neither accumulated net carbon (because of regular harvesting) nor released greenhouse gases during wildfires in significant quantities. Thus, after land is developed or farmed it makes no further contributions to greenhouse gas uptake or release in this analysis.

Carbon dioxide emissions due to land use conversion were estimated for farmland development using reported declines in agricultural carbon stocks at the county level for 1987, 1992, and 1997 from the Winrock study (2004).

Carbon dioxide emissions caused by vegetation removal for the conversion of undeveloped lands into farmland or developed areas were quantified using GIS analyses of SANDAG land use data at the parcel level for 1990, 1995, 2000, 2004, 2007¹⁸ and SANDAG projections for 2020.¹⁹ Lands classified as preserve open space (7603), landscape open space (7606), and undeveloped (9101) were all considered undeveloped, while all other land uses were considered developed. The change in developed land area was quantified by comparing 1990 and 2020 land use data and locating land parcels that had switched out of undeveloped designations. Intermediate year land use data was used to quantify the variability in rates of development during the 30-year period. Once “developing” land parcels were located in each period, they were overlaid with the county vegetation dataset described earlier to determine types and acreages of vegetation displaced. These acreages are multiplied by the biomass amounts (“fuel loading”) listed in Table 3 and multiplied by 0.4 to determine the mass of carbon displaced. As recommended by the CARB (Winrock) study, we assume that the carbon stock from land that is developed is immediately released as carbon dioxide to the atmosphere. Thus, the displaced carbon is multiplied by the factor 44/12 to determine the mass of CO₂ released.

Emissions due to forestry from slash decomposition and fuel wood were assumed to be zero because of the negligible amount of forest harvest that currently occurs in San Diego County.

Fire burn areas downloaded from the SANGIS website²⁰ were overlaid on vegetation maps by GIS to determine types of ecosystems burned each year from 1990 – 2003 and 2007. (Burn areas for 2004 – 2006 are not yet available. Average burn areas for the non-firestorm years 1990 – 2001 were used for this period.) Carbon dioxide and methane emissions released by wildfires in San Diego County were estimated using the method of Wiedinmyer et al. (2006), who uses the equation:

$$Emission = AB(wE_w + hE_h)F \times GWP$$

where A is the burn area of a given land cover class in hectares, B is the biomass per hectare (“fuel loading”), w is the woody fraction, h is the herbaceous fraction (where w + h = 1), E is the combustion efficiency of a given fraction, F is the emission factor for the greenhouse gas in question, and GWP is the greenhouse warming potential of the gas. Values for the variables B, w, E, and F (except F_{N_2O}) are taken from Wiedinmyer et al. (2006) and are listed in Table 3. GWP is defined as 1 for carbon dioxide. We used a GWP of 21 for methane and 296 for nitrous oxide. The result of the calculation is in units of kg of CO₂ equivalents, which is multiplied by 10⁹ to get MMT CO₂E.

Nitrous oxide (N₂O) emissions were estimated using the same method²¹ as in the CARB inventory. This method, where both carbon and N₂O emissions are in the same mass units, is shown below (Eq 2). If the carbon emitted term is removed from the equation, the result is an emission factor for N₂O which can be used in equation 1. This emission factor (after unit conversions) is listed in Table 3.

$$N_2O_{emitted} = \frac{Carbon_{emitted} \times 0.005 \times 0.01 \times 44}{28}$$

Fire emissions calculated using these methods for the firestorm years 2003 and 2007 were consistent with the CARB (Winrock) method for fires with an intensity between medium and high, which seems appropriate.

Limitations of the Methodology / Error Analysis

Results using the Wiedinmyer method have lower uncertainties than the CARB (Winrock) method, which failed to distinguish between different fuel types. The Wiedinmyer method is reliable to within a factor of 2, but has not been directly validated due to a lack of measurements. Thus, our calculated emissions due to development and fire have the same level of uncertainty. The methods of the Winrock study for estimating CO₂ uptake by vegetation have an estimated reliability of ±38%. Since we have extended this method to include chaparral, scrub and grasslands (based on Luo’s two 2007 measurements on chaparral ecosystems) our estimations of CO₂ uptake are also reliable only to within a factor of 2.

These uncertainties will be reduced only by measurements of biomass content, fire emissions, and CO₂ uptake in local ecosystems. Very few measurement studies have focused on the types of ecosystems that cover most of San Diego County due to their low biomass compared to forests.

3. Emissions From Livestock Management

San Diego County has a vibrant agricultural sector; however, much of the activity is associated with cut flowers and avocado farming, rather than typical field crops and large-scale livestock operations. San Diego County's relatively small livestock operations are mainly responsible for regional greenhouse emissions from the agricultural sector.

The statewide greenhouse gas inventory conducted by the California Air Resources Board (CARB) includes several different sectors of agricultural activity, including in agriculture, forestry, and other land uses sector. CARB's inventory includes the following emissions sources.

- Livestock emissions from enteric fermentation and manure management;
- Land emissions from forest land; and,
- Emissions from aggregate sources such as biomass burning, liming, managed soils, and rice cultivation.

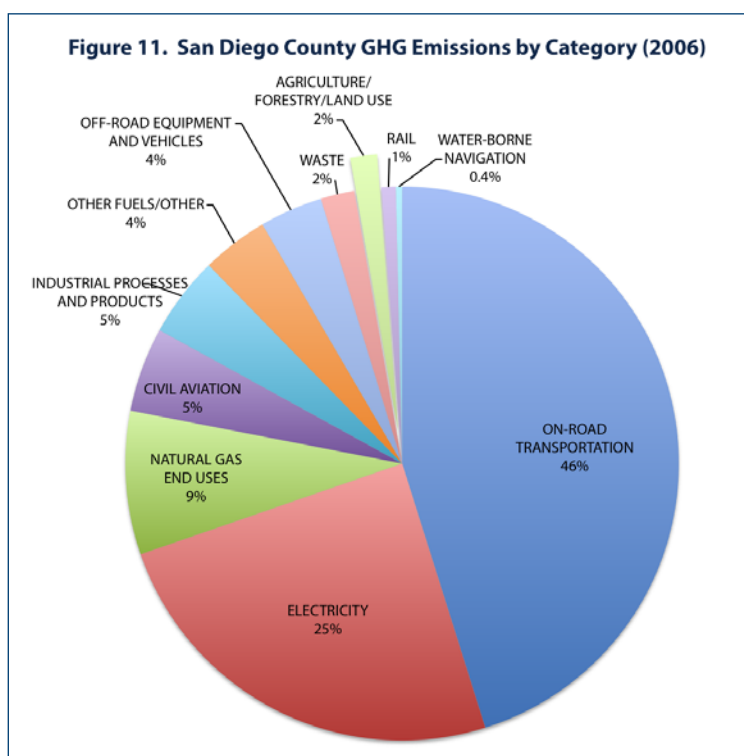
This section focuses on the livestock emissions. Land use is covered in the previous section, and data on biomass burning, fertilizer rates, and soils management were not readily available. Emissions from these activities are likely to be insignificant. Also, it is important to note that emissions included in this section do not include emissions associated with electricity, natural gas, and other fuel consumption by the agricultural sector. Emissions associated with these activities are captured in other sections.

3.1. Livestock Emissions Overview

Agriculture emissions make up only a small portion of the greenhouse gas inventory for San Diego. As seen in Figure 11, emissions from livestock are less than 1% of the total regional greenhouse gas emissions levels.

Livestock emissions have consistently been decreasing each year during the period of 1990-2006. Figure 12 shows this trend of declining emissions, which is directly proportional to the decrease in livestock populations over the years. This decrease is likely due to the displacement of farms by urban growth extending into rural areas of the county.

Projected emissions from the agriculture sector will be approximately 0.03 MMT CO₂E in 2020 under a business as usual scenario (Figure 2). Since agriculture emissions have actually decreased by 0.12 MMT CO₂E (79%) from 1990 levels, the AB 32 goal of 1990 levels has already been achieved. To get to the Executive Order goals of 80% below 1990 levels by 2050, emissions from this sector would have to be reduced just 1% more from 2020 levels, an additional reduction of just over 0.001 MMT CO₂E. Due to the existing downward trend in livestock population and emissions, it is likely that these levels will be achieved well before 2050.



3.2. Livestock Emissions by Sector

Livestock emissions are divided into two categories based on the emissions source: enteric fermentation and manure management. Enteric fermentation is defined as a fermentation process that takes place in the stomach of ruminant animals. This process produces methane that is released through belching and flatulence. Manure management is the process of gathering and disposing of manure from livestock. Management practices vary by type of livestock, but in the case of dairy cows, manure is often collected and stored in lagoons. As the manure breaks down, methane is released. As shown in Figure 13, manure management accounts for 65% of livestock emissions, while enteric fermentation accounts for just 35%.

As shown in Figure 14, the amount of emissions contributed by each animal type varies, in some cases dramatically. Dairy cows account for nearly 60% of greenhouse gas emissions from the manure management sector. Other cows (22%) and chickens (16%) are the second and third largest emitting class of animals in this sector. Enteric fermentation emissions in San Diego County come mainly from cows, with only an insignificant amount emitted from sheep and hogs. Other cattle, which are cattle not counted as dairy or beef, emit nearly 45% of all the methane from enteric fermentation, more than any other class of animal. Figure 14 shows this breakdown. It is also important to recognize the various populations of each animal type. Chickens greatly outnumber cows, hogs, and sheep in San Diego County.

Figure 12. GHG Emissions from Livestock in San Diego County

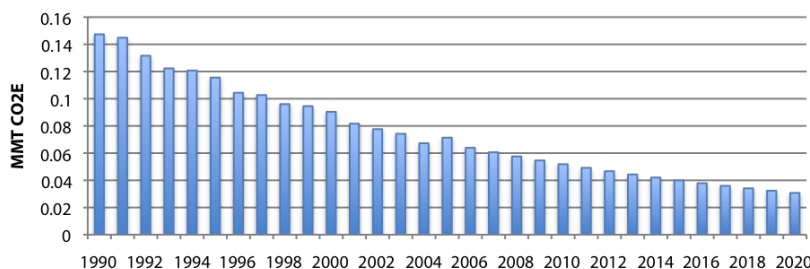


Figure 13. Breakdown of Livestock Emissions in San Diego County (2006)

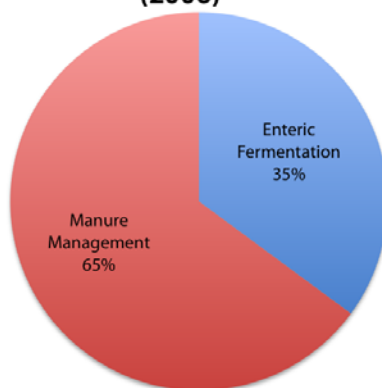


Figure 14. 2006 Manure Management Emissions for San Diego County

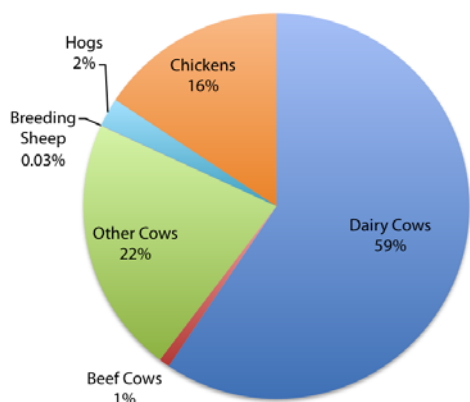
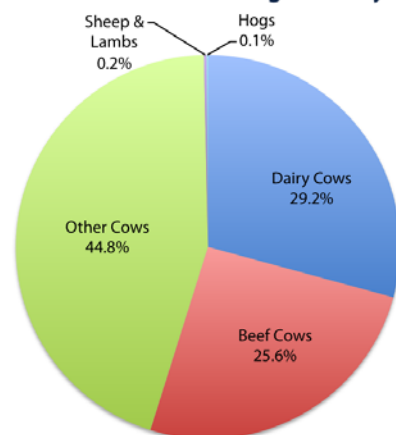


Figure 15. 2006 Enteric Fermentation Emissions in San Diego County



3.3. Livestock Emissions Reduction Strategies

Although livestock only account for a small percentage of overall emissions in San Diego County, many other parts of the state and country are conducting research on methods to reduce emissions in this sector. One strategy to reduce emissions from manure management that is being used in dairy cow operations is to collect manure and capture methane via anaerobic digesters for use in electricity production or for injection into the existing natural gas transmission system. Several large digester projects in the Central Valley of California will generate biogas that will be treated to natural gas quality and then fed into the natural gas supply system. One dairy in San Diego County (Van Ommering Dairy) already uses an anaerobic digester to capture biogas to generate electricity.

Other strategies also exist to reduce livestock emissions. The US EPA suggests improving the productivity and efficiency of livestock populations to reduce enteric fermentation emissions (CH_4).²² Efficiency can be improved by the following:

- Nutritional improvements
- Dietary supplementation
- Genetic improvements
- Grazing management
- Soil testing
- Water quality control

Other suggestions from the US EPA on manure management emission reductions for N_2O and CO_2 gases also include efficiency improvements and improved livestock management.²³

3.4. Livestock Emissions Calculation Methodology

The project team used data from two different sources to calculate livestock emissions: the San Diego County Crop Report²⁴ and U.S. Department of Agriculture (USDA) National Agricultural Statistics.²⁵ Neither data set was complete and some interpolation and extrapolation was necessary to complete each set. The sets were then combined to serve as the basis for livestock emissions calculations. USDA data included information for the years 1990-1992 and 2001-2007, so we used a linear regression analysis to estimate livestock populations for the missing years, 1993-2000. USDA livestock population data included only the categories of dairy cows, beef cows, and all cattle. To determine the population of the “other cow” category, we subtracted data from the “milk (dairy) cows” and “beef cows” categories from the “all cattle” category included in the USDA data set.

The San Diego County Crop Report provided livestock population data for sheep and lambs, hogs, and chickens for the years 1995-2006. A linear regression analysis was used to backcast livestock population to 1990.

3.4.1. Emissions Calculations

To calculate livestock emissions, the project team used a direct calculation provided in the CARB statewide greenhouse gas inventory. For each sector CARB provides a ‘per unit activity’, which is based on the total

emissions for that sector divided by the unit of activity. As an example, in 1990, California's 1,115,000 dairy cows emitted 143,547 tons of CH₄ (3,014,481 tons CO₂E), which yields per cow emissions of 128,741 g of CH₄ per head of Dairy Cows (2,703,571 g CO₂E per head of dairy cows). We multiplied the total head count for each animal type by this CARB activity factor to estimate emissions from livestock in San Diego County.

3.4.2. Livestock Emissions Projections

The project team projected both manure management and enteric fermentation emissions estimates to 2020 using a logarithmic decay model. First we calculated the log of historical emissions and plotted the results versus the year. From this plot, we performed a linear regression analysis to fit the line. From this line, the antilog of the slope and y-intercept component (right side of equation) was taken. The year 2020 was then plugged into the equation and the emissions for that year were predicted. This model produced more reasonable projections than a linear model.

End Notes

1. Development data is available for 1990, 1995, 2000, 2004, 2007, and 2020.
2. Total land area is 2.73 million acres.
3. Agricultural lands are classified as "developed" in the map. Forests are highlighted in yellow (conifer) and bright green (hardwood).
4. Developed and agricultural lands are not included. Total uptake is 0.68 MMT CO₂.
5. Figure 6 includes areas that have been converted or are projected to be converted from undeveloped to farmland or developed land, 1990 – 2020, by vegetation class.⁸
6. Mensing, S.A., J. Michaelsen, and R. Byrne, A 560-year record of Santa Ana fires reconstructed from charcoal deposited in the Santa Barbara Basin, California. *Quaternary Research*, 1999. 51(3): p. 295-305.
7. <http://www.sangis.org/>
8. 2004 – 2006 burn areas are unknown. The 1990 – 2001 average was inserted in Figure 7 for these years due to lack of data.
9. The "shrub" designation refers to chaparral.
10. 2004 – 2006 burn area data is not yet available. Average emissions from 1990 – 2001 have been substituted for these years.
11. Brown, S., T. Pearson, A. Dushku, J. Kadyzewski, and Y. Qi. 2004. Baseline Greenhouse Gas Emissions and Removals for Forest, Range, and Agricultural Lands in California. Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research. 500-04-069F
12. SANDAG GIS shapefiles download available at: http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/senlu.asp
13. Statewide vegetation data with 100 m resolution available from CA DFFP's Fire and Resource Assessment Program (FRAP) available at: http://www.frap.fire.ca.gov/data/frapgisdata/download.asp?spatialdist=2&rec=fveg02_2
14. New category.
15. Classification specified by Winrock study (2004).
16. Wiedinmyer, C., et al., Estimating emissions from fires in North America for air quality modeling. *Atmospheric Environment*, 2006. 40: p. 3419-3432.
17. Luo, H., Carbon Dynamics and Its Environmental Controls over Southern California Chaparral Ecosystems Using Eddy Covariance Techniques., Ph.D. thesis in Ecology. 2007, San Diego State University.
18. SANDAG GIS land use data downloaded at: http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/landHistorical.asp
http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/landHistorical.asp (1990 - 2000)
http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/land.asp
http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/land.asp (2004 - 2007)
19. Schafer, E., SANDAG, personal communication to D.O. De Haan. GIS-compatible files posted to SANDAG ftp website: <ftp://ftp.sandag.org/pub/DEHAAN/> (2008)
20. <http://www.sangis.org/>
21. Crutzen, P.J. and M.O. Andreae, Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. *Science*, 1990. 250: p. 1669-1677.
22. U. S. Environmental Protection Agency. <http://www.epa.gov/rlep/faq.html#3>
23. Ibid.
24. See http://www.sdcounty.ca.gov/awm/crop_statistics.html.
25. U.S. Department of Agriculture National Agricultural Statistics Service
http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp#top